

BBC



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The untold story of how they conquered the competition



Helen Czerski
BBC presenter's brand new column begins

Be perfect!
Why we make mistakes and how to stop them

Measuring machines
Recording the cosmos one atom at a time

FOCUS

SCIENCE AND TECHNOLOGY

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ISSUE 251 / FEBRUARY 2013 / £3.99



BBC one **BRIAN COX IS BACK!**

WONDERS OF LIFE

The amazing story of how our senses evolved

PLUS Brian Cox's close encounter with 'alien' intelligence

INCREDIBLE JOURNEY

One man's mission to the heart of an active volcano



YOUR QUESTIONS ANSWERED

- Is it faster to fly east or west?
- What is a funny bone?
- Does Wi-Fi affect your health?



THIS ROBOT COULD SAVE YOUR LIFE

How remote presence will link doctors and patients

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At the heart of the image



WELCOME TO FOCUS



PHYSICIST. BROADCASTER. POP star. Prof Brian Cox is all of those. 'Biologist', on the other hand, isn't a word you'd associate with the science superstar. Yet in his latest BBC series *Wonders Of Life*, he tackles the natural world.

It's a surprise, perhaps, but it works. In the sneak preview I saw, his outsider's perspective made for a refreshingly different kind of

wildlife documentary. He did, however, have expert help. One of the consultants who worked on the series was evolutionary biologist Matthew Cobb. We asked Cobb to do the same for *Focus* as he did for Brian Cox – share his expert knowledge on the senses. Turn to page 34 for his article and see page 40 for our chat with Cox himself.

Another scientist who's a familiar face on TV – from programmes such as *Operation Iceberg* and *Dara O Briain's Science Club* – is Dr Helen Czerski. Helen has the rare gift of making science both interesting and easy to understand, so I'm delighted she's joined the ranks of *Focus* contributors. Her new column, Hidden Treasures, will examine the things we see every day and explain the science behind them. This month, Helen asks why snow *isn't* invisible. Find out on page 31.

There's much else to enjoy, including a review of the revolutionary Lytro camera that lets you change the focus of a photo *after* you've taken it. Until next month,

Graham

Graham Southorn, Editor

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Dean Burnett

A lecturer in psychology and neuroscience at Cardiff University, Dr Burnett writes

a mind-bending blog called Brain Flapping, which is hosted on *The Guardian* website. You'll also find his thoughts on Twitter at @garwboy.



Matthew Cobb

The Professor of Zoology at the University of Manchester was an expert consultant on

Brian Cox's new BBC series *Wonders Of Life*. He's also the author of several books, including *The Egg And Sperm Race* and *Life's Greatest Secret*.



Helen Czerski

A physicist and oceanographer, Dr Czerski investigates the science of ocean bubbles at

the University of Southampton. Her TV appearances include *Operation Iceberg*, *Orbit* and *Transit Of Venus*, and she tweets from @helenczerski.



Cherry Lewis

Dr Cherry Lewis is an honorary Research Fellow in the School of Earth Sciences at

the University of Bristol. Her book on geologist Arthur Holmes, *The Dating Game: One Man's Search For The Age Of The Earth*, was published in 2000.



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Turn to p32 for an exclusive look at the frontiers of virology with **Prof Vincent Racaniello**

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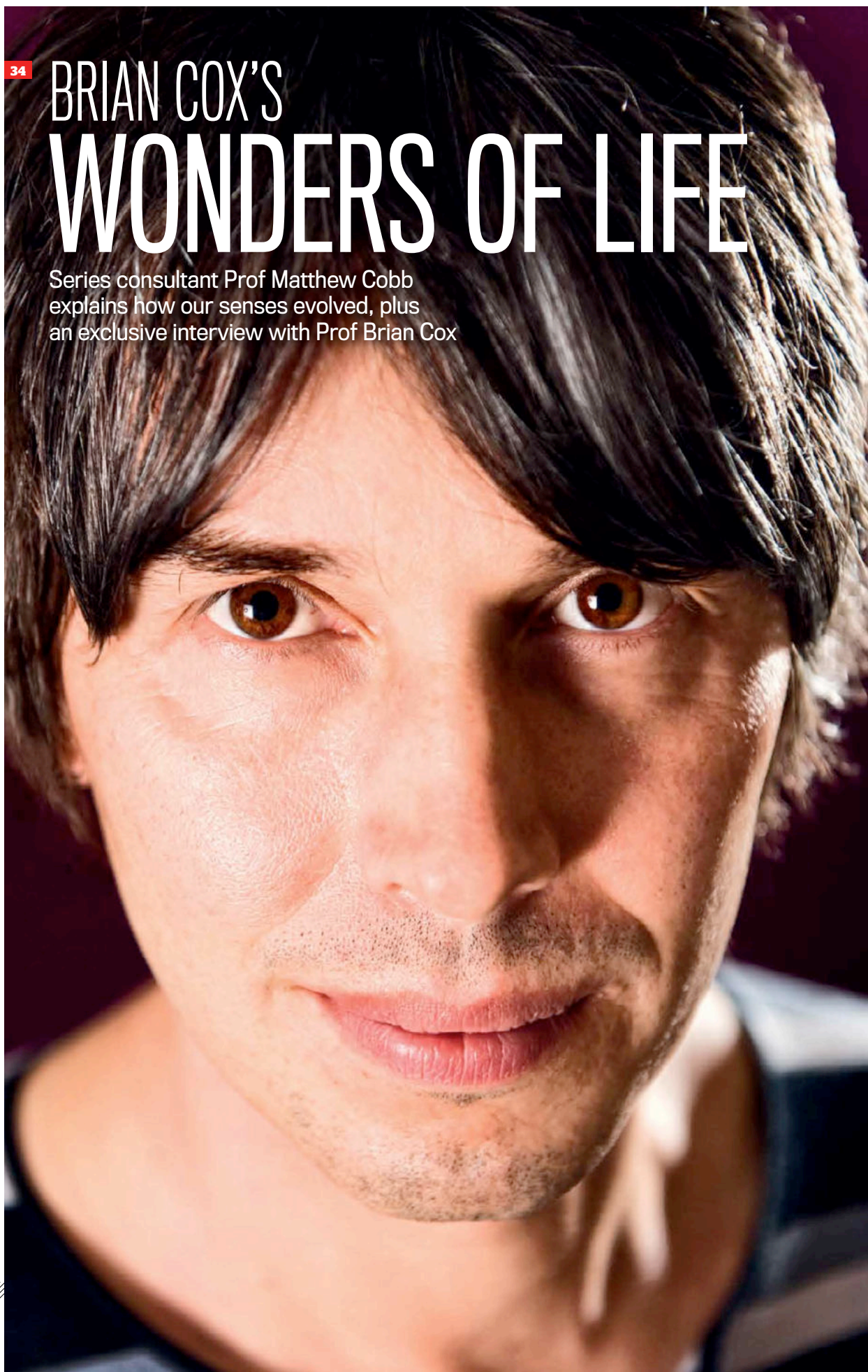
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Series consultant Prof Matthew Cobb explains how our senses evolved, plus an exclusive interview with Prof Brian Cox



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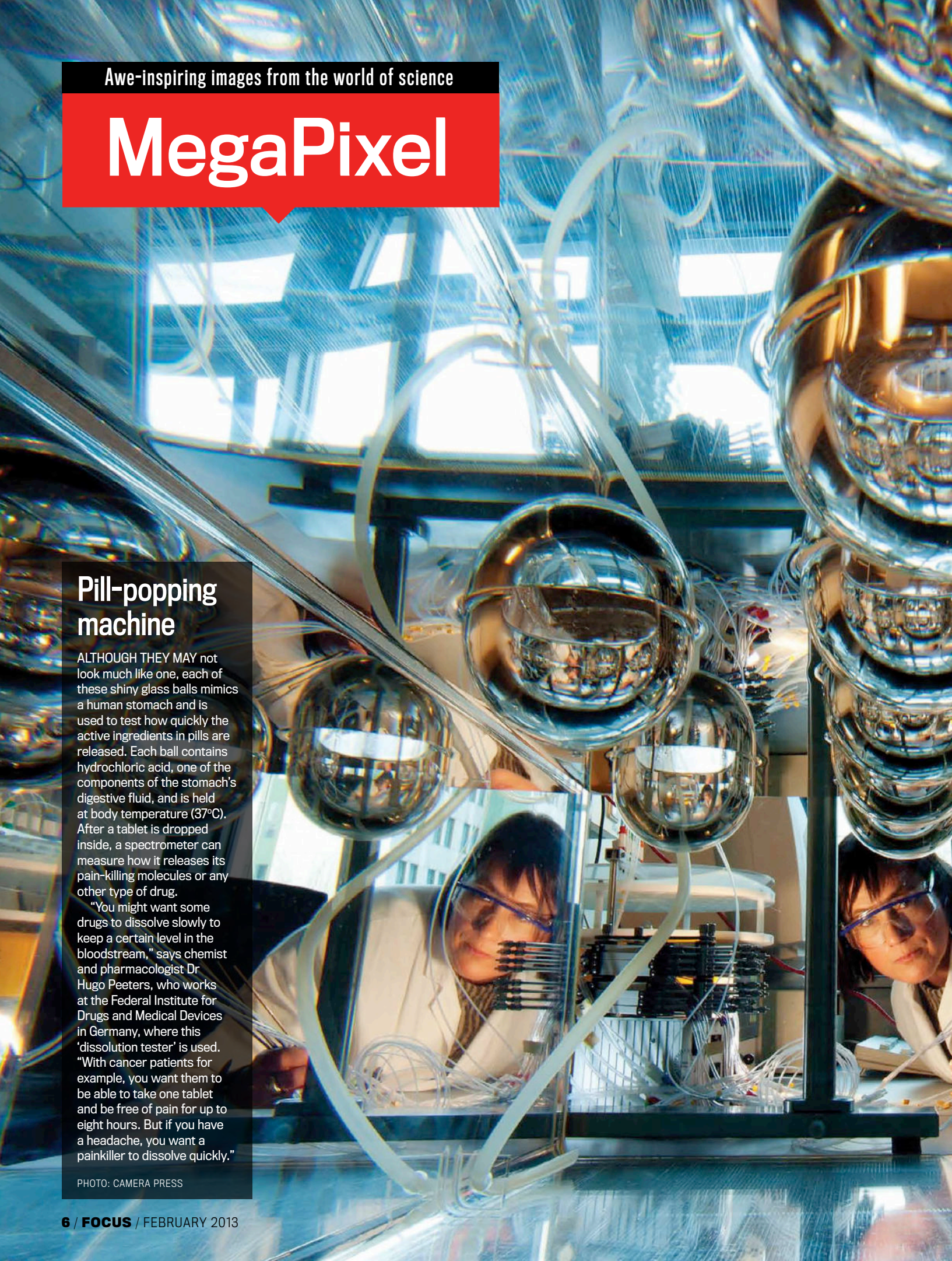
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MegaPixel

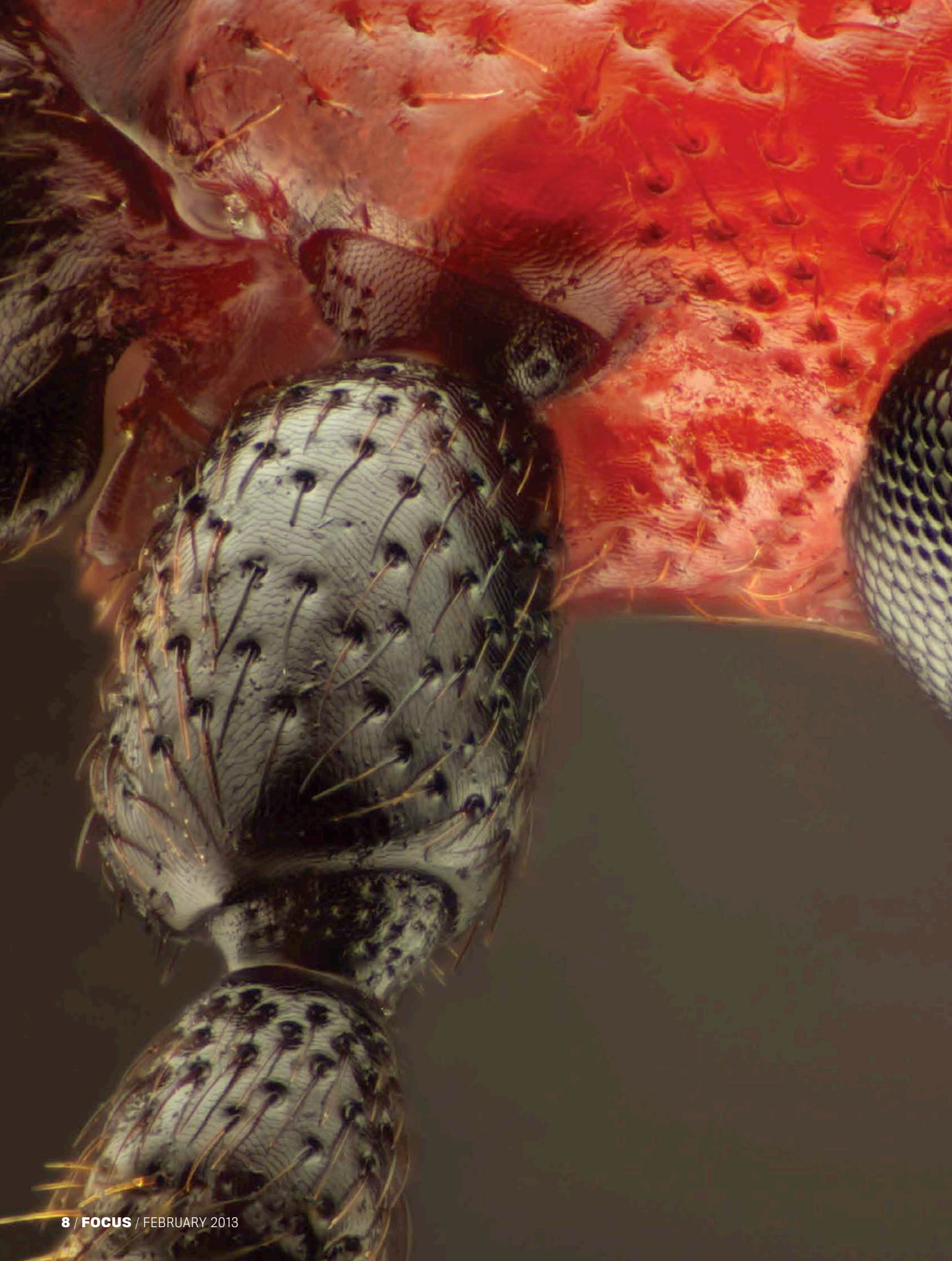
Pill-popping machine

ALTHOUGH THEY MAY not look much like one, each of these shiny glass balls mimics a human stomach and is used to test how quickly the active ingredients in pills are released. Each ball contains hydrochloric acid, one of the components of the stomach's digestive fluid, and is held at body temperature (37°C). After a tablet is dropped inside, a spectrometer can measure how it releases its pain-killing molecules or any other type of drug.

"You might want some drugs to dissolve slowly to keep a certain level in the bloodstream," says chemist and pharmacologist Dr Hugo Peeters, who works at the Federal Institute for Drugs and Medical Devices in Germany, where this 'dissolution tester' is used. "With cancer patients for example, you want them to be able to take one tablet and be free of pain for up to eight hours. But if you have a headache, you want a painkiller to dissolve quickly."

PHOTO: CAMERA PRESS







MegaPixel

A mite-y beetle

IT'S NOT OBVIOUS this close up, but this is the head of the cinnabar flat beetle (*Cucujus cinnaberinus*), which lives on decaying wood throughout central Europe. Even if we showed you its whole body, you might not recognise the

insect because it's endangered. On the far left is the edge of its mouthparts, next to that the base of a long antenna and finally the compound eye.

The white creature climbing the beetle's face is a mite. It's a common pest, says Dr Teresa Bonacci, an ecologist at the University of Calabria in Italy. "Beetles that live in these habitats tend to be infested by mites," she says.

The reason for the beetle's red colour isn't clear. Insects that live in hidden sites are often camouflaged – bright colours are usually the preserve of poisonous or foul-tasting species. While it can play dead when threatened, it could also be trying to deter predators by appearing poisonous.

PHOTO: NIKOLA RAHME/NIKON



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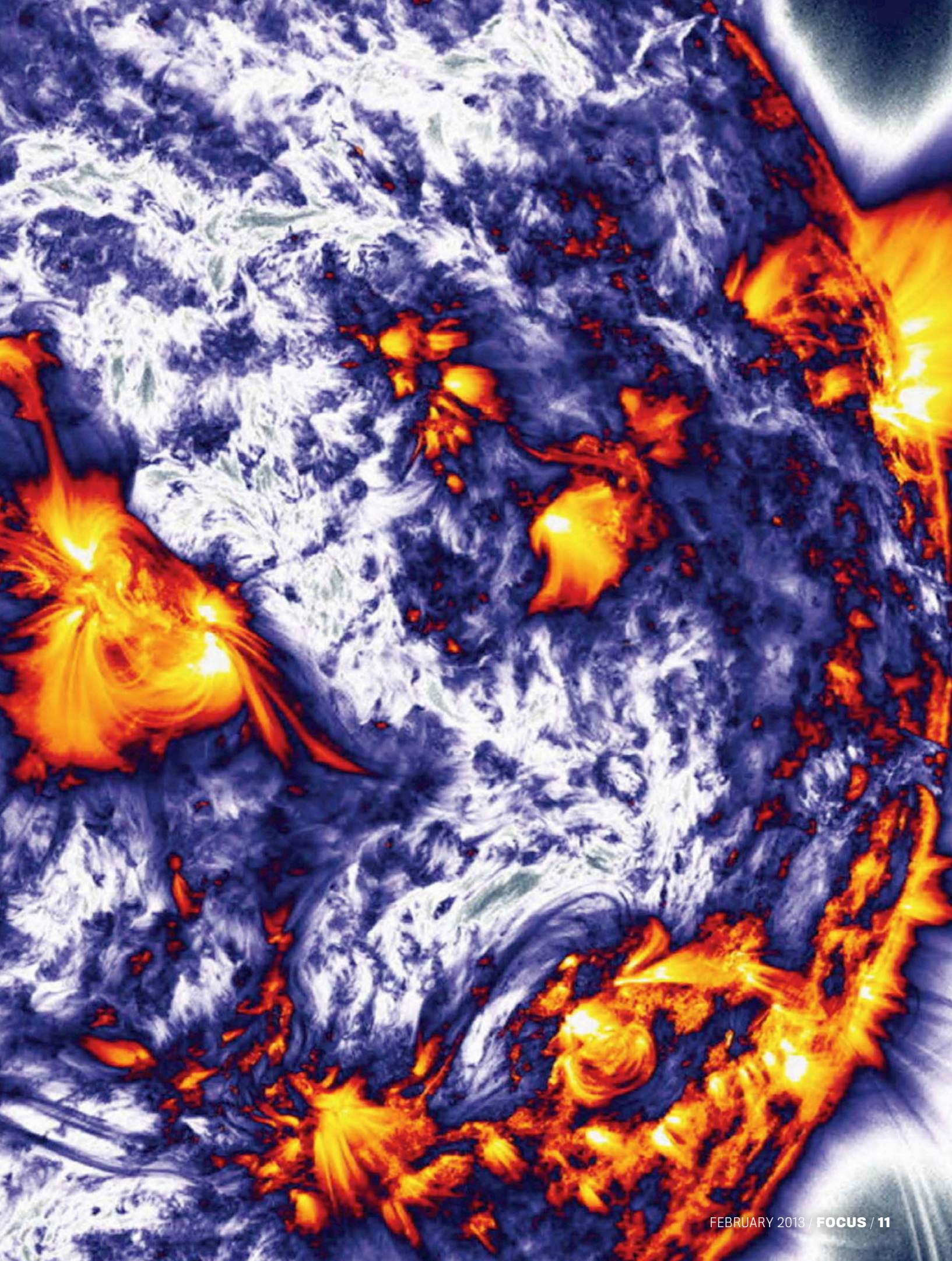
Star struck

THIS EXTRAORDINARY picture of the Sun was taken by NASA's Solar Dynamics Observatory, a spacecraft designed to study our star in unprecedented detail. A gradient filter – a tool found in standard photo editing software – was then used to enhance areas of contrast to pick out interesting features.

The prominent orange patches are known as coronal loops. "When these loops become highly twisted they release huge amounts of energy in the form of light across the whole electromagnetic spectrum, as well as billions of tonnes of solar material," says Dr Alex Young, a solar physicist at NASA's Goddard Space Flight Center.

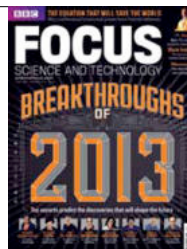
Coronal loops are huge arcs of solar matter that are constrained to travel a particular path by the Sun's magnetic field. Watching the loops enables physicists to study the otherwise-invisible field that powers solar flares and coronal mass ejections – massive eruptions on the Sun. These huge releases of energy can knock out communication systems and power grids.

PHOTO: NASA



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Your opinions on science, technology and our magazine



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Letters may be edited for publication

MESSAGE OF THE MONTH



DNA-based data storage would be clean and compact

One giant leap for data

As Andy Ridgway's article 'Entire book encoded in DNA' (October, p18) points out, the next great advancement in data storage will not come from improvements in standard materials used to build electronic devices, such as silicon chips, magnetic tapes or floppy disks. Based on George Church's work, it appears that nature's ultimate molecule, DNA, will be the material that transforms digital storage media. Molecular biology will transform the computer, electronics and information technology industries and

DNA-based nanotechnology will play a major role in the long-term storage of data. DNA will be used as the basic building block for storing ultra-large amounts of data. Compared to other storage methods, DNA-based data storage chips would cost less and have no environmental toxicity. The central molecule of life, DNA, will be the material that results in the next great leap in information storage technology.

Claude E Gagne, New York Institute of Technology



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YOUR COMMENTS ON OUR FORUM

On www.sciencefocus.com/forum, we asked: **Is fracking a good idea or a potential disaster?**

M Paul Lloyd I think it is a crackpot idea born of panic over the looming energy shortfall. It is being billed as great for the consumer but, if some experts are right, it's risking some unpleasant consequences. One day we might just find the ground beneath our feet a lot less stable than we are used to.

Lateralman Perhaps following what Iceland is doing with geothermal energy is the way forward. This is a cheap, limitless clean energy source that doesn't deplete our scant resources on the surface or pollute the environment. Ideas are needed to tap into this more safely and efficiently.

Flakkarin The problem with fracking is that it's too new, growing too fast, and often not properly regulated. The industry will tell you that fracking has been around for 60 years, but new tech (ie horizontal drilling) allows pretty prolific extraction, which makes the resource viable.

Don't panic

As human beings, we do love to frighten ourselves. That's presumably the reason for the enduring success of disaster movies, horror comics, ghost stories, fairground rollercoasters... and now worthy science magazines.

I'm writing, of course, about the apocalypse scenarios by Alok Jha in December's issue (p35). Being microwaved by a nearby supernova could have been added to the list. Yet in truth I don't believe that. Unless we get hit by something the size of Mars, we will survive in the organic smear covering the third rock that we call home. I know that NASA is well aware of the nemesis asteroids and assure us

that a close encounter is not likely to happen any time soon. But city-busting Tunguskas [a famous impact event in 1908] that know our postcode are rather more problematic. Perhaps a Patriot missile interceptor system might be a good idea: one that could detect and fire automatically, yet be clever enough not to engage any incoming friendly aliens.

David Storer, Totton

Coral con artists

Your coral article (December, p23) included a classic case of misleading graphics. The numbers showed a decline of area of 50.7 per cent between 1985 and 2012, but the graphic showed a circle with its diameter reduced by 50 per cent – which of course has 25 per cent of the area! To make amends, how about an article on how scientific information can be distorted by advertisers and lobbyists using this type of misleading graphic?

Niall Caldwell, Edinburgh

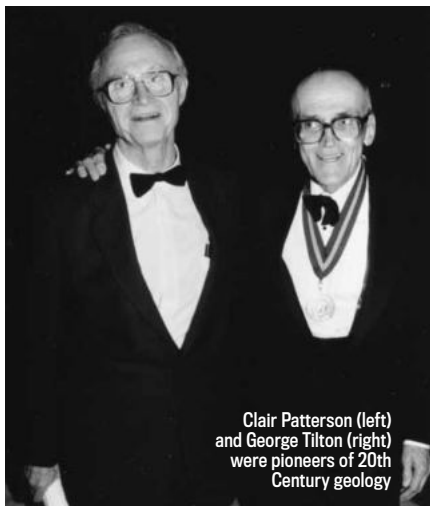
You're quite right, Niall. In this case it was human error on our part, not an attempt to mislead, but well spotted! – Ed

Whose hand?

In the December issue of *Focus*, in the article about the age of the Earth (p107), the picture of Clair Patterson shows him with a hand on his back. I was curious whom it belonged to.

Duncan Burgess, Shetland

Picture editor James Cutmore replies: *The man to the right of Clair Patterson, as you can see in the full photo, is geologist George Tilton, photographed in 1995. Tilton was best known for pioneering the uranium-lead isotopic method of determining the age of rocks.*



Clair Patterson (left) and George Tilton (right) were pioneers of 20th Century geology

Shaken, not stirred

I read *Focus* for the first time today and found it fascinating. Just one little moan: in the excellent article 'End of the world' (December), who decided to put an ad for Epson with the words 'PROFESSIONAL LASER KILLER' right at the end? For a heart-stopping moment I thought my desk printer was a world destroyer!

Charlie Mulholland, 70 and shaken!

Destroyer of cities

In the October issue of *Focus*, Sue Bowler's article 'The mark of mankind' (p53) made me think that the chances of one of the world's major cities being destroyed are quite high. This is starting to look even more likely after the tsunamis in Japan and Hurricane Sandy in New York. It begs the question: should we be building our cities in safer areas?

Duncan Burgess, Shetland

YOUR COMMENTS ON TWITTER

On www.twitter.com/sciencefocus, we asked: If you had a 3D printer, what would you make with it?

StevieB64 More 3D printers! Until I have a self-replicating army of awesome tech

DaveHenniker I'd 3D print people and objects scanned by a consumer version of Windows Kinect, assuming it's ever created (not holding breath)

Richdav I'd print myself a set of @ProfBrianCox teeth!

iLauraMuir Intricate cake decorations

callmeharvey Spare parts

BurnsideScience Obviously a dinosaur! Why anything else?

AndyDevanney I'd have a go at printing Kelly LeBrock *Weird Science* style!

TomHanson1985 I want a T. rex skeleton

SnuttsD If the tech becomes cheap enough, everyone could have their own action figure – imagine that would make a brill profile pic!

Carry on the conversation using the hashtag #3Dprinters

FOCUS

SCIENCE AND TECHNOLOGY

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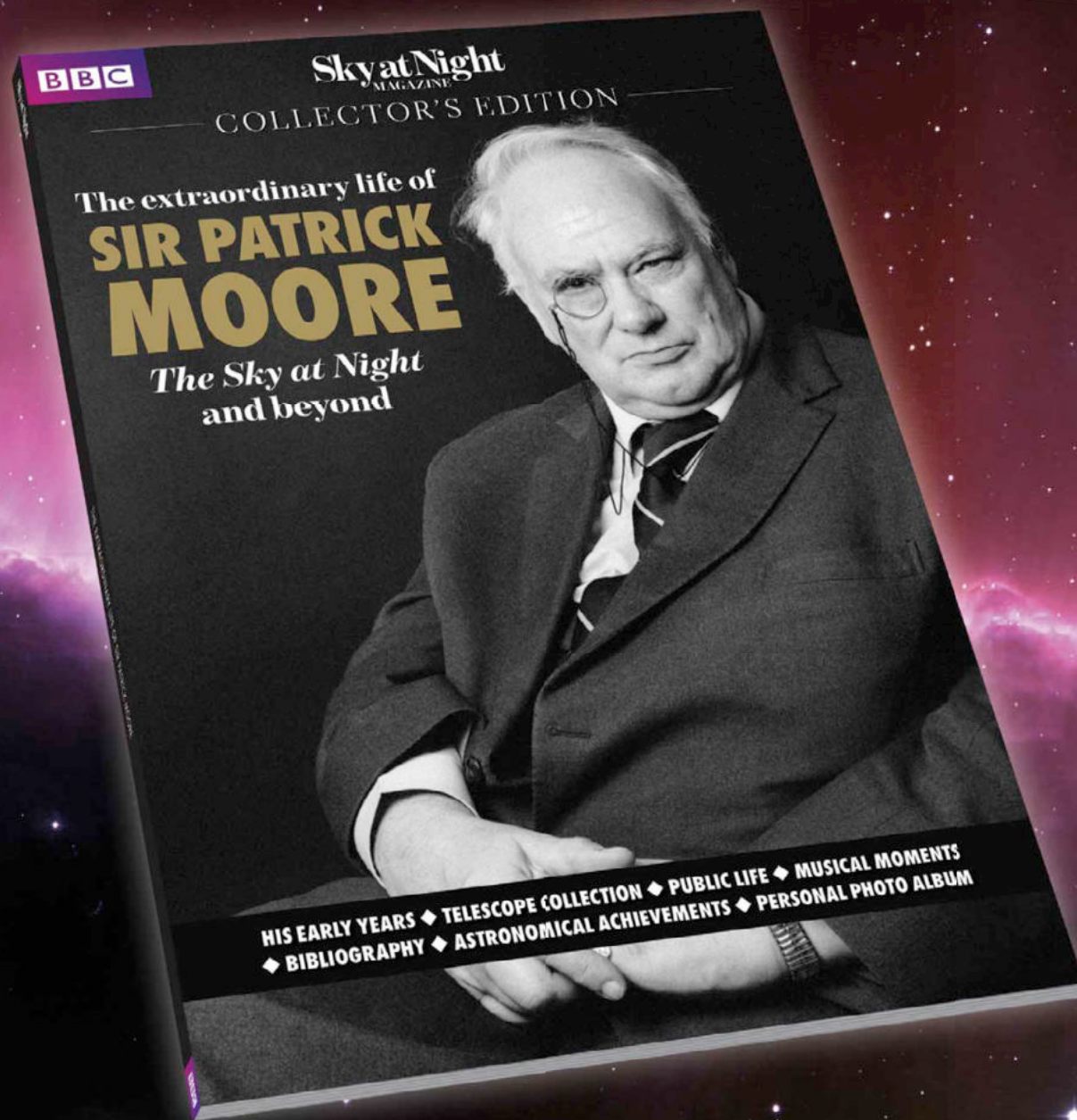
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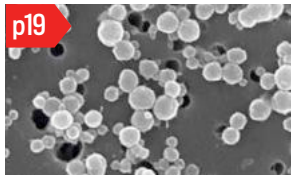
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DISCOVERIES

News and views from the world of science



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What organisms in Lake Vida, Antarctica, could tell us about life on other planets

THE MAGIC OF MAGGOTS

How maggot slime helps wounds heal more quickly



p20

PLANTS IN SPACE

Cress: the final frontier! Why NASA is getting green-fingered



p25

THE BIG STORY

Oldest dinosaur discovered

Bones held in storage for decades provide insight into start of the dinosaur era



A humerus (arm) bone of *Nyasasaurus parringtoni* - the earliest dinosaur known. The different colours in the cross-section (right) reveal disorganised bone fibres, indicating rapid growth

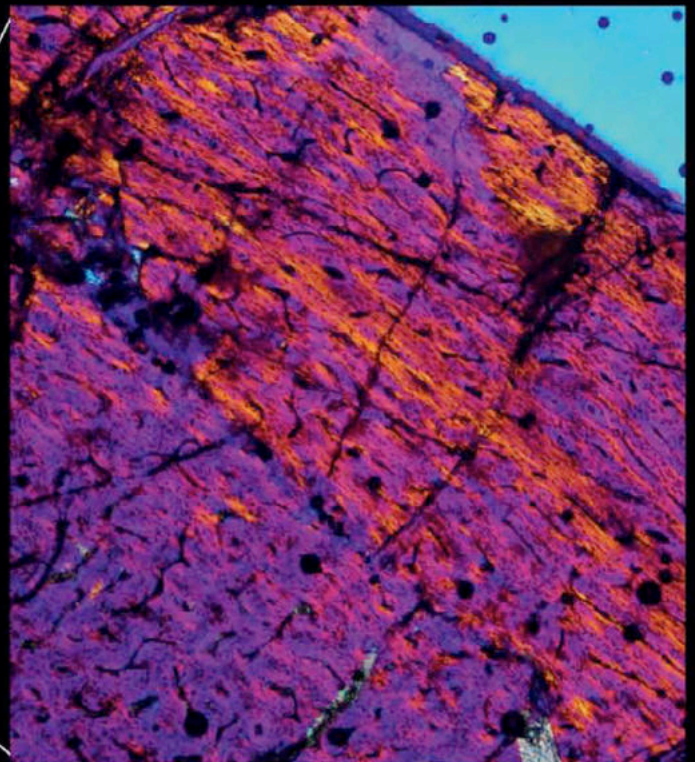
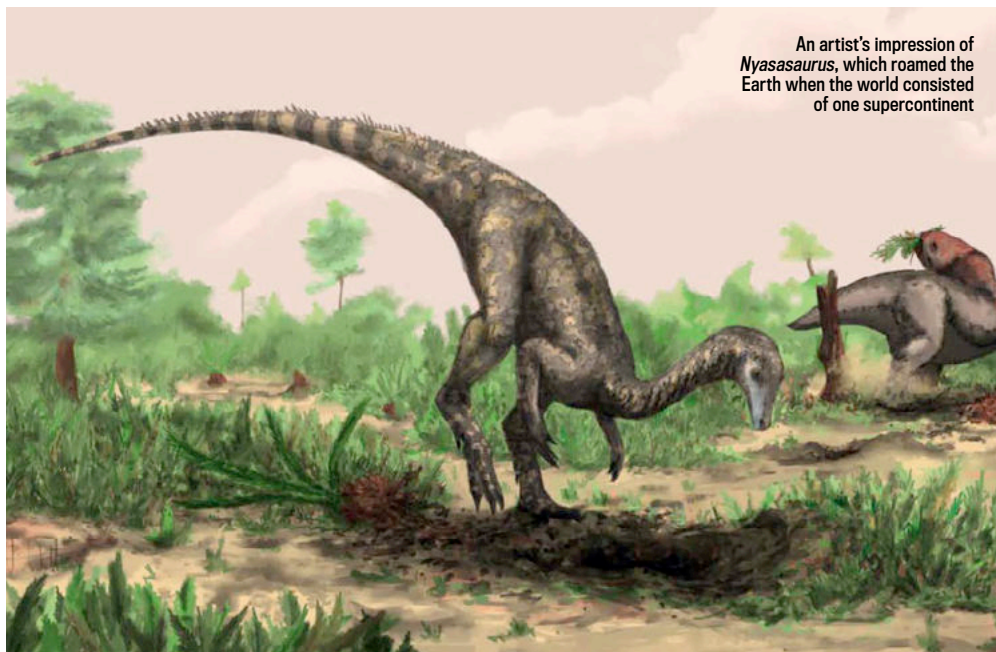


PHOTO: NATURAL HISTORY MUSEUM



An artist's impression of *Nyasasaurus*, which roamed the Earth when the world consisted of one supercontinent



FOSSILISED BONES THAT have been stored in a museum for decades could belong to the earliest dinosaur ever found, a new study reveals. An international team of palaeontologists believes the fossils are of a creature that lived 245 million years ago – 15 million years earlier than any previously known dinosaur.

The fossils are of a Labrador-sized animal's arm bone and sections of bone from the back and hips. They were dug up in Tanzania in the 1930s by Rex Parrington, a palaeontologist at the University of Cambridge, and were first studied by Parrington's PhD student Alan Charig in the 1950s. But Charig died before he could publish his research, and it is only now that a detailed analysis of the fossils has been published. It shows that the bones share many features with the earliest dinosaurs. The species, named *Nyasasaurus parringtoni*, would have lived in the early part of the Middle Triassic period – its bones were found with others from that time.

"Although the fossil material is limited, it is very distinctive and completely unlike that of other contemporary reptiles," says Dr Paul Barrett, a dinosaur expert at the Natural History Museum in London, where the fossils

are stored. "In particular, a prominent crest on the upper arm bone is a feature found only in *Nyasasaurus* and other dinosaurs."

The bone tissue has a woven texture and large spaces for blood vessels, showing the animal grew quickly – also typical of dinosaurs. Another fossil in South Africa includes several bones from the neck of a *Nyasasaurus* and it, too, shows dinosaur-like features. As early dinosaurs were lightly built, omnivorous or predatory bipeds, it is probable that this species was like that, too.

The limited number of *Nyasasaurus* bones found means that while the characteristics identified so far are consistent with it being a dinosaur, insufficient details can be picked out to confirm that beyond doubt. Further fossils would provide definitive proof, but more recent hunts have failed to turn anything up.

"We have not found anything clearly assignable to *Nyasasaurus* in our field trips," says Dr Sterling Nesbitt at the University of Washington, who led the research. "But we are planning on going back to Tanzania as soon as time and funding allows."

DARREN NAISH

Turn to page 54 to find out how dinosaurs conquered the world.



TIMELINE

How our knowledge of the earliest dinosaurs has evolved

1963

Osvaldo Reig describes the early dinosaur *Herrerasaurus ischigualastensis*, which lived 231 million years ago in what is now Argentina.

1970

Staurikosaurus, an agile predator that lived 225 million years ago, is described by Edwin Harris Colbert from the American Museum of Natural History.

1993

Paul Sereno describes *Eoraptor*, a small, bipedal creature which lived in what is now Argentina around the same time as *Herrerasaurus*.



2011

Eodromaeus, a small predator that lived 230 million years ago, is described. Its fossils were discovered in 1996 but misidentified initially as *Eoraptor*.

2011

P. barberenai, which lived 228-230 million years ago, is described, marking a stage between the earliest dinosaurs and later, specialised species.

2012

Nyasasaurus parringtoni, thought to have lived 245 million years ago, is first described. It is either the first dinosaur, or a close relative of them.



ANALYSIS

Mike Benton



Professor of palaeontology at the University of Bristol



THE *NYASASAURUS parringtoni* fossils show that something very dinosaur-like

lived 15 million years earlier than had been understood before. But we can't be sure whether this really is a dinosaur or a close relative. The authors of the research are justifiably careful and say the limited remains are all consistent with it being a dinosaur, but there's no single clinching characteristic. Finding a more complete skeleton of *Nyasasaurus* would tell us exactly what kind of creature it is.

Whether *Nyasasaurus* is a dinosaur or near-dinosaur, it brings the diversification of the dinosauriforms – the bigger group to which dinosaurs belong – into a period that's 15 million years earlier than we'd thought. More specifically, it brings the diversification into the 10 million years of recovery time after the largest mass extinction event of all time, which happened 250 million years ago.

As many as 90 per cent of all species were wiped out by climate change caused by massive volcanism at the end of the Permian period. Life had to recover after that profound blow and this was a long and protracted process. Entirely new ecosystems emerged and the new research shows just how important that time of turmoil was.



WHAT DO YOU THINK?

Give us your opinions on dinosaurs at facebook.com/sciencefocus

🕒 1 MINUTE EXPERT

The Earth's hum

What's that?

The surface of the Earth is constantly being vibrated by ocean waves and heavy road traffic, resulting in seismic waves travelling through the planet. These waves are known as 'Earth's hum', or ambient seismic noise.

Why is the hum in the news?

Seismologists at Université Joseph Fourier in Grenoble, France say they have found a way to use it to reveal the Earth's internal structure.

So what did they do?

They installed 42 seismic recording stations in Finland and compared the signals at each. By filtering out seismic waves from earthquakes, they reconstructed the ambient noise. The way these waves travel is determined by the interior's physical properties, such as rock composition. This meant that the extent of the mantle – the layer below the crust – could be calculated.

Why is this significant?

Traditionally, researchers have analysed seismic waves from earthquakes. This makes data hard to come by because large 'quakes are rare. It also means that studies of the core have been restricted to locations where earthquakes take place. Using the hum avoids these problems.



Drilling at Lake Vida began in 2005, but the study's results have only just been published

Biology

Antarctic lake offers clues to extraterrestrial life

DEVOID OF OXYGEN, it's pitch black, over five times saltier than seawater, and has been isolated under a layer of ice for nearly 3,000 years. Yet, in Antarctica's Lake Vida, scientists have found life, raising our hopes of finding it elsewhere in the Solar System.

Researchers who drilled into the lake in 2005 and 2010 have discovered 32 types of bacteria, including one not closely related to any known species. It's believed the bacteria could be living off dissolved organic carbon, deposited when the lake was first sealed off, or off hydrogen produced by reactions between the brine and underlying sediments.

"The lake is essentially frozen through to the bottom," says project co-leader Dr Alison Murray from the Desert Research Institute in Reno, Nevada. "However, it has liquid brine in fissures and channels in the ice, and the salinity of this brine is high enough to remain liquid at temperatures of -13°C ."

The research is helping scientists probe the boundary between where life can and cannot exist. "Finding this limit will help us when we're looking for life on other planets and moons," says Dr Peter Doran, the project's other co-leader from the University of Illinois at Chicago. "On Mars, for example, there might be buried ice deposits like this with associated brines. If there's life down there that's living off hydrogen or is self-sufficient, it could keep going for a long time."

The team's results were announced just as a British team was preparing to drill into Antarctica's Lake Ellsworth. Unlike Lake Vida, which has gradually frozen into a layer of ice up to 27m thick, Ellsworth formed below 3km of glacier ice, and may have been isolated for hundreds of thousands of years. But as *Focus* went to press, drilling at Ellsworth had been put on hold due to technical difficulties with the equipment.

JAMES LLOYD

WHO'S IN THE NEWS?

Professor John Grotzinger

Geologist at California Institute of Technology



🔴 What did he say?

The geologist and chief scientist on NASA's Curiosity mission intimated that data from the rover's Sample Analysis at Mars (SAM) instrument was looking pretty significant. "This data is gonna be one for the history books. It's looking really good," he told a reporter for NPR, an organisation that provides news to radio stations in the USA.

🔴 What was the reaction?

Grotzinger's comments prompted headlines and blogs around the world, with speculation that NASA was about to announce the discovery of life on Mars.

🔴 So what was actually being announced?

That the rover had discovered evidence of chlorine, sulphur and

water in the Martian soil, as well as simple organic compounds – chemicals containing carbon. But NASA's scientists have since made it clear that they can't yet be sure whether the carbon in the samples originated on Mars, or was simply carried up there from Earth. Grotzinger said he had simply been excited to see the rover's instrument was working properly.



Maggot slime aids healing by suppressing certain immune system proteins

Medicine

The magic of maggots revealed

MAGGOTS MAY NOT be the prettiest of creatures, but they have been used to treat infected wounds for centuries. Now researchers have discovered why maggot slime is such an effective healer – it suppresses the immune system.

Records of maggots being used to treat wounds date all the way back to ancient Aboriginal and Maya cultures. They were later used to treat Napoleon's injured soldiers, and in both World Wars. Maggot therapy declined in popularity during the 1940s, once penicillin started to be produced on an industrial scale, but the treatment bounced back again in the 1990s as it provided a means of fighting bacteria that had developed a resistance to antibiotics over time.

As well as munching on rotting tissue, maggots also secrete a slime which has been known for some time to speed up the healing process. How this happens, though, was not clear. So Dutch and Swiss researchers, led by Dr Gwendolyn Cazander at Leiden University Medical Center in the Netherlands, set out to discover the secret of slime's success.

First, they siphoned slime from lab maggots and added it to blood that had been donated by healthy adults. They then measured the amount of complement proteins in the blood – proteins that are part of the immune system and help fight infections. The researchers discovered that maggot slime tears these complement proteins apart, reducing levels by as much as 99.9 per cent. This would help to calm inflammation in a wound, leading to faster healing. "In some cases, when people have a wound there is an overreaction of the complement system, which results in prolonged inflammation and tissue damage instead of healing. The maggots reduce complement activation, and so stimulate the wound healing process," says Cazander.

The next step will be to pinpoint the compounds in the slime responsible for suppressing the immune system. These compounds could ultimately wind up in a new drug, which would enable patients to heal more quickly without the need to endure maggots and their slimy secretions.

JAMES LLOYD

DIGITAL WORLD

Science on the web

100,000 STARS

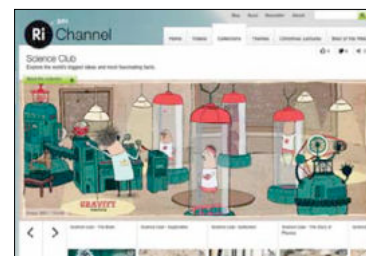
workshop.chromeexperiments.com/stars

Start at the Sun, zoom out to see the names of nearby stars, then keep going to see the density and location of over 100,000 stars. Finally, you'll see the complete Milky Way. You'll need to be using the Chrome browser to view this 3D space map, but it's worth it.

SCIENCE CLUB COLLECTION

richannel.org/collections/2012/science-club

The BBC series *Dara O Briain's Science Club* may be over, but the show's animated short films are still available to watch on the Ri Channel, an online offering from the Royal Institution. Each film takes a theme – from Albert Einstein to genetics – and brings it to life with animated characters.



The Ri Channel hosts the animations from BBC Two series *Dara O Briain's Science Club*

STORY COLLIDER PODCAST

storycollider.org

Everybody has stories to tell about science, and the people behind Story Collider, a monthly storytelling event in Brooklyn, New York, want to hear them. The show recently made its London debut, and stories from that night are now available as part of Story Collider's weekly podcast.

PSYFILE

youtube.com/user/psyfile

Ever been tempted to ask a psychologist if they know what you're thinking? This new video series explores topics such as mind-reading and time perception with experts from the University of Manchester's School of Psychological Sciences.

KELLY OAKES

Materials science

Graphene electronics comes one step closer

GRAPHENE IS ONE step closer to fulfilling its potential in electronics, thanks to a discovery that shows how it can be turned into a switch. The development could lead to the much-feted material replacing silicon inside our computers.

A one-atom-thick sheet of carbon atoms, graphene is able to carry electrons at ultra-high speeds. The trouble is, materials used in transistors – the fundamental building block of electronic devices – must be able to act as electronic valves, controlling the amount of current flowing through the

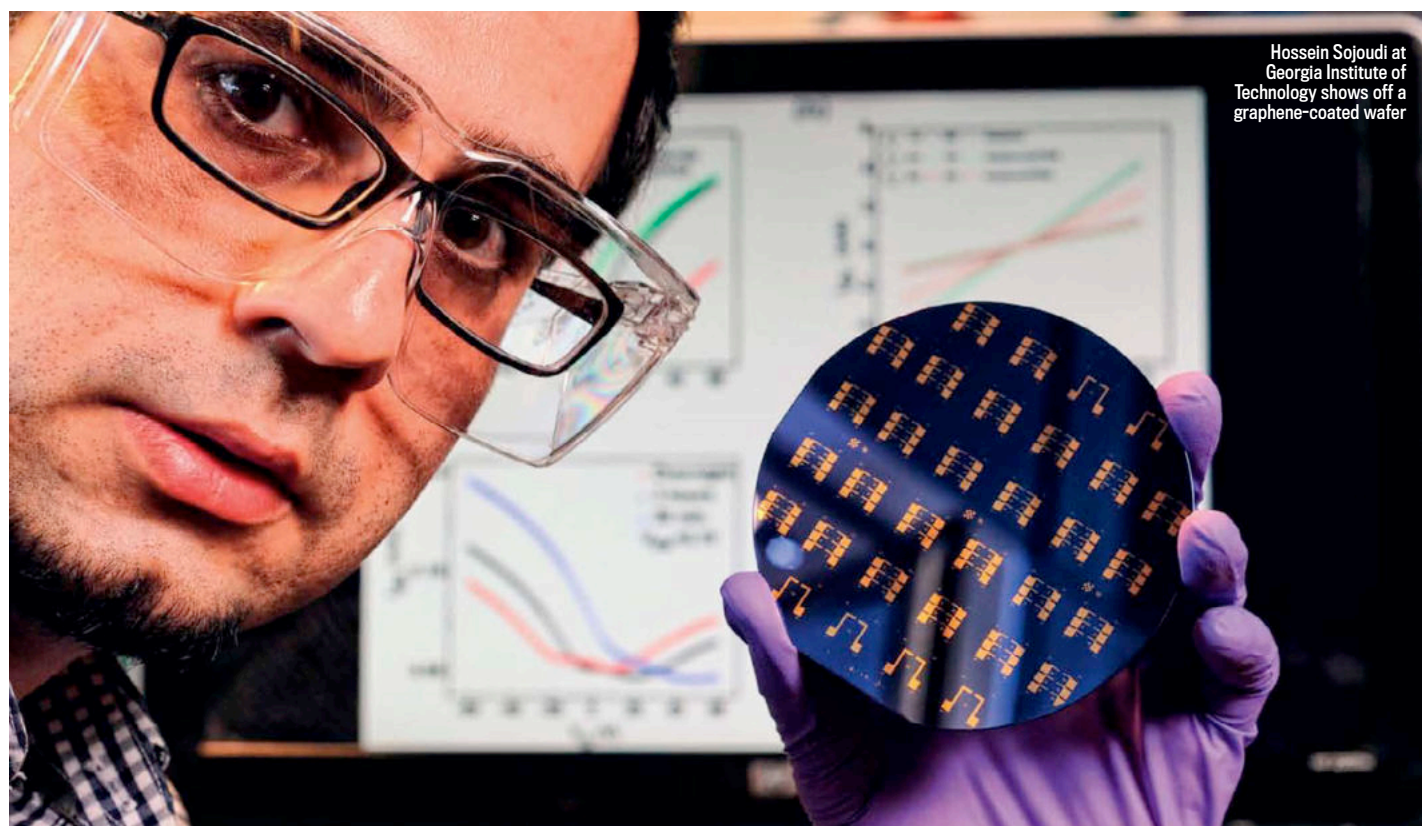
circuit. This requires a difference or ‘band gap’ between the energy of the electrons that don’t move and the energy needed for them to move freely. Silicon’s band gap makes it perfect for this job, but graphene typically has a band gap of zero.

Previously, solutions have involved adding an insulating layer to two layers of graphene, but this would limit how small devices could be. Now researchers in France and the US have grown graphene sheets on tiny trenches or grooves, 18 nanometres deep (1 nanometre is one-

billionth of a metre). Where the graphene dips into the trench, it develops a band gap and acts as a semiconductor. The speed of a processor is limited by the speed its switches operate. Graphene could therefore lead to faster computers in the long run.

“I don’t think graphene will replace silicon any time soon,” says Professor Ed Conrad at Georgia Institute of Technology in Atlanta. “But because graphene can switch faster and at lower power, I see it operating in very high-end computers.”

JAMES LLOYD



Hossein Sojoudi at Georgia Institute of Technology shows off a graphene-coated wafer

NEWS IN BRIEF

Some like it hot, some like it chilli

• If you have a taste for hot chilli, it’s likely to be due to your personality. US researchers gave nearly 100 volunteers liquid samples of capsaicin – the compound that makes chilli hot – and a questionnaire rating their ‘sensitivity to punishment and reward’. It was the thrill seekers who liked the hot stuff the most.

World’s arthropod diversity calculated

• Up to six million species of arthropod (invertebrates, with jointed exoskeletons) exist. Entomologists carried out a count in the Panamanian tropics and found 6,144 species. For every species of tree there were 20 species of arthropod, so the global number could then be calculated from the number of tree species in the world.

Mars’s scars are revealing

• Craters left on the surface of Mars by ballast dropped from the Curiosity rover as it landed will provide insights into the planet’s atmosphere. Knowing the exact size and weight of the blocks that created the craters will provide a clearer insight into the atmosphere than studying asteroid impact scars.



An impact crater on Mars, caused by Curiosity dropping ballast as it came in to land



HOT TOPIC

Should fully autonomous weapons be banned?

→ WEAPONS THAT MAKE their own decisions on whether or not to shoot should be pre-emptively banned, says the campaign group Human Rights Watch. In its report, *Losing Humanity: The Case Against Killer Robots*, the organisation says autonomy would pose a danger to civilians during times of conflict.

So-called 'human out of the loop' or fully autonomous weapons (FAWs) would be capable of selecting targets and firing without any human input.

But the new report, published jointly by Human Rights Watch and the Harvard Law School International Human Rights Clinic, calls for an international treaty that would ban their use.

"Giving machines the power to decide who lives and who dies on the battlefield would take technology too far," says Steve Goose, Arms Division director at Human Rights Watch.

No FAWs are currently operational but advanced military nations have already deployed precursors of them.



WHAT DO YOU THINK?

Let us know your opinions at twitter.com/sciencefocus using the hashtag #hottopic, and facebook.com/sciencefocus

Your Tweets and Facebook posts



David Kelly: Any conflict would be a walkover for those nations that have the capability. This type of weapon would make war horrifyingly easy.



Kieron Donlon: Reminiscent of OmniCorp's ED-209, it seems eminently possible that the first target of a truly autonomous weapon would be its creator.



Ste Sigurnjak: People would still die with or without them – friend, foe and neutral. But they would remove individual responsibility for a kill.

WHAT THE PAPERS SAY

HENRY GEE

New research from leading science journals



Some of us may be hard-wired to eat too much

D ID YOU SWEAR on New Year's Day to go on a diet, fall off the wagon and get even porkier? Did this make you sad? You are not alone. But just to rub salt into the wound, you know all those headlines recently about fat people being more jolly? As headlines often tend to do, they rather over-egg the pudding.

Tracing the headlines to their sauce – er, sorry, source – they come from a recent study by Dr Zena Samaan at McMaster University in Canada and her colleagues, that was published in the journal *Molecular Psychiatry*. It shows that a form or 'variant' of a gene called FTO, known to be associated with some forms of obesity, has a small protective effect against depression. But this does not mean that fat people are more jolly. *Au contraire* – on the whole, fat people tend to be more depressed than thin people. All it means is that people with this variant are less likely to be depressed than one might otherwise expect. The effect is quite small – less than seven per cent.

FTO, intriguingly, is expressed – or 'switched on' – in the human brain, and

there are increasing numbers of reports of its association with psychiatric disorders and even the formation of the brain itself. Some variants are associated with a reduction in speech fluency and brain atrophy, where the brain shrinks due to a loss of cells. Complete absence of the gene is lethal, characterised by microcephaly – pathologically tiny brains – and other problems with how the brain is put together.

Scientists and clinicians have long been interested in the interaction between diet, obesity and one's mental state. For example, there's a well-known phenomenon called social facilitation of eating, in which people generally have bigger helpings when in company than alone.

What the recent research on FTO does is shed a little more light on the association between obesity and depression. Most interestingly, to my mind, it shows that there's a link between our attitude to food and the way our brains are wired up, in some quite fundamental way.

A note of caution is necessary, though. Nobody yet thoroughly understands how depression, obesity and FTO are functionally linked. In other words, what FTO actually does to influence obesity and mental state. It is a sure bet that many, many other genes will be involved. So it's not worth rushing out and getting your DNA tested for FTO just yet.

Disclaimer: I am both overweight and clinically depressed myself... and find the symptoms of the latter alleviated by cake.

Henry Gee is a palaeontologist and evolutionary biologist, and a senior editor of the journal *Nature*

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- Diameter of Primary Mirror 150mm
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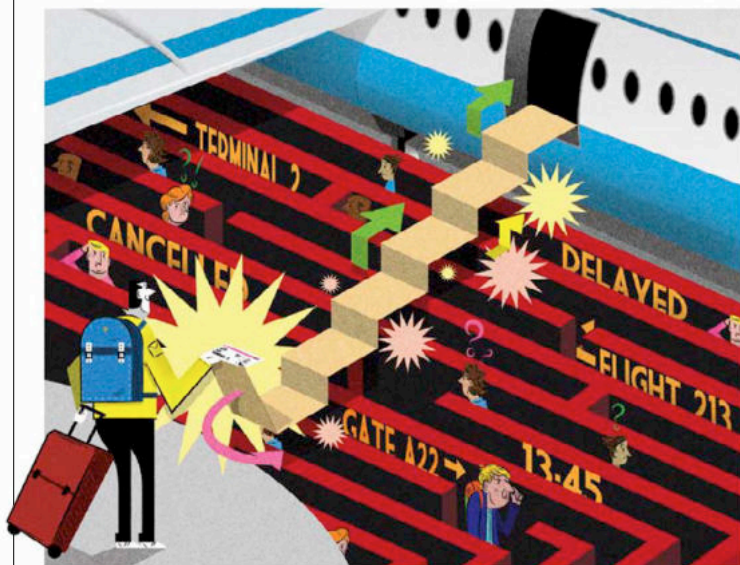
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PATENTLY OBVIOUS

Inventions and discoveries that will change the world with James Lloyd



Travel data gets personal

LET'S FACE IT, travelling by plane can be a bit of a hassle. The walls of displays you have to watch at the airport to get your flight information; the seemingly endless and impenetrable labyrinth of corridors. And let's not get started on those queues.

Thankfully, help could be at hand in the shape of personalised travel information display systems. US communications and engineering company Aeronautical Radio Incorporated (ARINC), based in Maryland, has applied for a patent for a device that will scan a passenger's travel documents and

then display bespoke information about his or her journey ahead, drawing these details from disparate sources.

The company envisages that such units – which would provide travellers with additional information such as the latest status of their flight, the expected waiting time at security and the current weather conditions at their destination – could be installed in locations such as train stations and car rental offices, as well as in airports themselves.

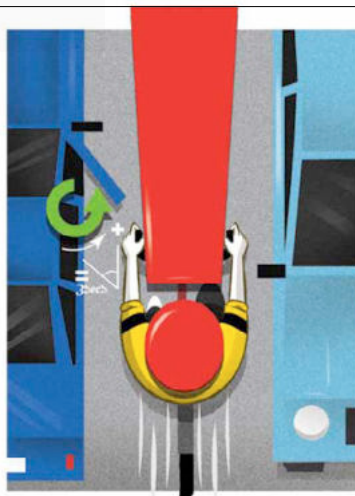
Patent application number:
GB 2491107

Danger, car door!

THERE YOU ARE, cycling along and minding your own business, when a car door opens in front of you. What happens next can go one of two ways: either you swerve and carry on your merry way, or you crash with potentially disastrous consequences. But now German company Bosch hopes to patent a system that can provide a warning to nearby cyclists and pedestrians that a door is about to swing open, so they can take appropriate evasive action in good time.

The technology only generates a warning when a cyclist is close enough to a car to get hit. Radar or infrared sensors (Bosch says several systems could be used) detect someone nearby on foot or on a bike. If the system believes a door may be opened, perhaps through a seatbelt being unclipped or a proximity sensor detecting a hand moving towards a door handle, the alarm is raised.

Patent application number:
GB 2491258



Radiators power up

RADIATORS ARE OFTEN installed below windows, to counteract the cold air coming through the glass. This, says UK inventor Francis Leggat, presents an opportunity. If a photovoltaic cell is fitted to a radiator, leaving enough space for the heat to escape, it can capture incoming sunlight and convert it into electricity to charge a battery, which can then be used to charge mobile phones and tablets.

Patent application number:
GB 2490897



THEY DID WHAT?!

Pictures of people scratching shown to volunteers

What?

Thirty volunteers were shown pictures of ants crawling on a

hand and someone scratching an insect bite, to see if it made them scratch a part of their body.

What happened? Researchers from Liverpool John Moores University and the University of Manchester watched the volunteers and found that images of itchy things, such as crawling insects or diseased skin, made people feel itchy. But it was

only the sight of other people scratching that caused volunteers to actually scratch, in some cases when they didn't realise it.

What was the point?

First, it shows that, just like yawning, scratching can be contagious. Second, this insight into the causes of scratching could help with the treatment of skin conditions.

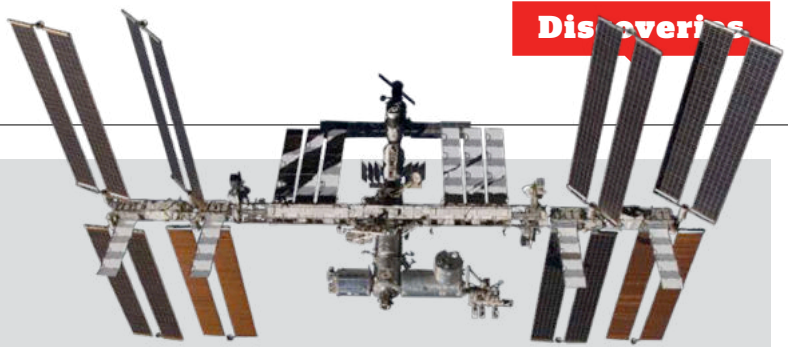


GRAPHIC SCIENCE

Seeing research differently

SPACE PLANTS GROW DIFFERENTLY

SEEDS OF A small flowering plant have been flown into space to monitor the effects of zero gravity on their growth. Biologists at the University of Florida flew two types of thale cress (*Arabidopsis thaliana*) to the International Space Station (pictured inset), where they were grown in a transparent nutrient gel by astronauts who captured the progress of their roots and stems using time-lapse video. Identical batches of plants were also grown at Ground Control on Earth in identical conditions. The results show that even a variety of plant of the same species can react to weightless conditions differently.

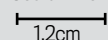


As we leave Earth's orbit, we will take plants with us. These findings, as well as previous work by us and by others, show that although plants respond with changes in their metabolisms, they can in fact grow just fine.

Dr Anna-Lisa Paul, University of Florida Genetics Institute



Scale: 1.2cm = 1cm of plant growth



Waviness of roots reflects waviness in space or Earth

Variety: Wassilewskija

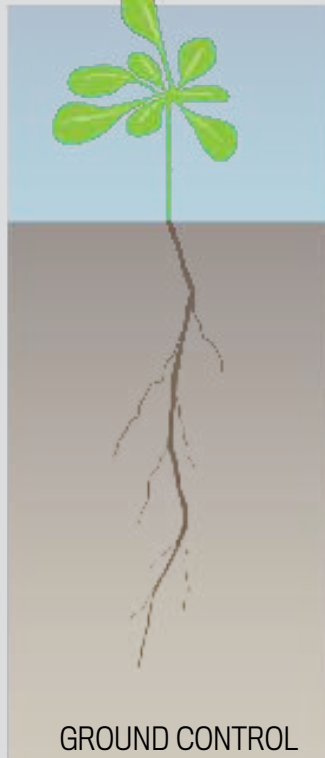


GROUND CONTROL

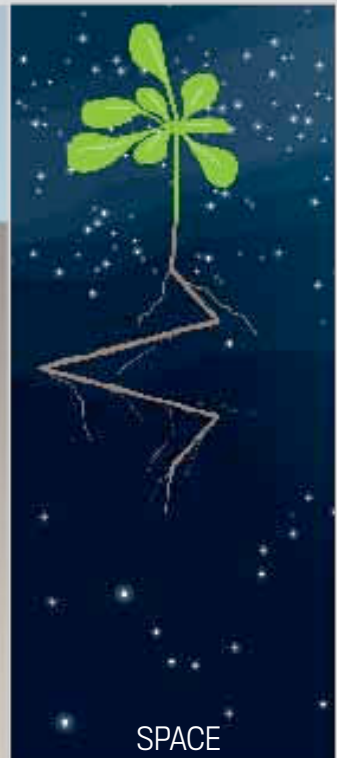


SPACE

Variety: Columbia



GROUND CONTROL



SPACE

NEWS IN BRIEF

Pluto's got plenty of atmosphere

• Pluto's atmosphere is twice as big as was thought, extending over 10,000km (6,200 miles) into space. US physicists combined two models of the dwarf planet's atmosphere to provide a better estimate of the rate molecules escape into space. The rate is slower than was believed, resulting in a much larger atmosphere.



The surface of Pluto (artist's impression)

Scans predict problem drinking

• Could a brain scan reveal if you're prone to alcoholism? Analysis of fMRI scans of Duke University students in the US suggests so. Only students with overactive 'reward circuitry' in a region known as the ventral striatum, coupled with underactive fear circuits in the amygdala, developed a problematic habit.

Butts keeps parasites at bay

• Birds line their nests with cigarette butts to drive parasites away. Ecologists in Mexico measured levels of cellulose acetate – found in the butts – in the nests of two bird species. The more there was, the fewer parasitic mites the nest contained. Smoked butts seem to be most effective.

SIR PATRICK MOORE

4 MARCH 1923 - 9 DECEMBER 2012

The face of astronomy on BBC television for over 50 years, he leaves behind a significant scientific legacy

FEW NAMES HAVE become as synonymous with a subject as Sir Patrick Moore's has with astronomy. For 55 years, he was the face of *The Sky At Night* on the BBC. "It was his enthusiasm, aided by his unique staccato delivery, that made him such an engaging broadcaster," says his co-presenter, Doctor Chris Lintott. "He genuinely couldn't understand why anyone wouldn't want to know how the Moon formed, or what an asteroid was, and when he spoke, everyone did want to know."

While Patrick's impact as a populariser of astronomy is clear, what's not so widely known is his contribution to science – a contribution that ties him to the Apollo Moon landings.

Patrick's biggest obsession as an astronomer was the Moon. He submitted his first paper to the British Astronomical Association (BAA) at the age of 14. It described small craters in the Mare Crisium – one of the dark plains on the lunar surface. After World War II, he set up a 12.5-inch telescope at his home in East Grinstead and joined the BAA Lunar Section. Fascinated with the limb, the outer edge of the Moon, he viewed it under different angles of 'libration' – the Moon's rocking motion. Normally, only 50 per cent of the Moon's surface can be seen but, over time, libration reveals 59 per cent. For Patrick, this provided a window on lunar features that are usually hidden from view.

After one session at the eyepiece, when he'd drawn part of the Moon's eastern limb, he noticed something that was missing from official maps – a ringed basin. The BAA confirmed the observation and Patrick subsequently submitted a paper to the BAA. He suggested that this be called Mare Orientale, the 'Eastern Sea'. Patrick later acknowledged he wasn't the first to find it, but he did more than anyone to bring the name Mare Orientale into general use.

It wasn't long before Patrick's maps attracted the attention of the superpowers. In 1959, the USSR approached Patrick for his sketches. Using his drawings, they were able to recognise features in photos taken by their new space probe, Lunik 3. In return, the Russians made

their images available to the BBC, and the first pictures taken by Lunik 3 were transmitted during a live broadcast in October 1959, a moment Patrick counted as one of the highlights of *The Sky At Night*. Five years later, NASA's Ranger 7 probe photographed the Moon's surface up-close. The American space agency also requested observations by Patrick, among others, and the cumulative knowledge led ultimately to Apollo 11's Moon landing in 1969.

END OF AN ERA

Once space probes had photographed every part of the lunar surface, the era in which amateur astronomers could discover new features on the Moon was over. But Patrick could still record something no probe could have photographed by making sketches. Mysterious changes on the lunar surface, which Patrick dubbed transient lunar phenomena (TLP) in 1968, occur when features on the Moon are briefly obscured. One theory was that volcanic activity was releasing gases that disturbed the lunar dust or created a gaseous glow. Today, several areas on the Moon are closely monitored but the phenomenon's existence remains controversial.

Patrick's gaze was not solely fixed on the Moon. In the '50s, it was discovered that Jupiter emitted radio bursts, but no-one knew if they came from the whole planet or were associated with specific features. Patrick helped find out. Volunteers timed when notable features crossed Jupiter's central meridian – the imaginary line down the middle of the planet – and the data was analysed by radio astronomers. They found no link with Jupiter's Great Red Spot or any other features. Years later, it was found that the radio bursts were in fact linked to the position of Jupiter's moon Io.

Patrick's observational accuracy and patience led to his discoveries. But his greatest legacy is the way he inspired so many people to take up astronomy, both as a hobby and a profession. Chris Lintott summed it up: "He had such an impact on so many people, astronomy will be a quieter, sadder, smaller world without him." ■

YOUR MEMORIES

We asked for your favourite moments of Patrick's career



Grant Brown I watched the Moon landings with Sir Patrick commenting. Black and white and completely hypnotic. Fantastic experience. Will never forget it.



HAR-V The 'Suns, Space Ships and Bug-Eyed Monsters' episode [of *The Sky at Night*] with Michael Bentine (1977). Recommended viewing.



Tony McDevitt When I was a lot, lot younger and watching *The Sky at Night* in black and white, you always felt he loved what he was doing.



Matthew Hall GamesMaster!



Catherine Donald My favourite memory of Sir Patrick was seeing him play the xylophone like a demon at a variety show in the '80s.



SIR PATRICK IN FOCUS

A long-time contributor, his writing graced our magazine

Patrick was always happy to write for *Focus*. He wrote book reviews and opinion columns, and occasionally more in-depth pieces. His typed copy would always be faxed to our offices (often way ahead of deadline), and was in his own inimitable



style. Even in print, you could hear his voice.

In 2002, on the 10th anniversary of *Focus*, Patrick was one of the luminaries selected to predict what the world would be like in 10 years' time. He spoke of his hope that a probe could be sent to Mars to bring back samples that would determine whether there was any trace of life. "Consider this: the last unmanned Mars probe cost 1/40th of a nuclear submarine," he said. His writing was always enriched by his experiences. "I remember talking to Orville Wright once," he said, "and he was so sick that the aeroplane had been

used for warfare." He had also met Albert Einstein, asking him to describe infinity in non-mathematical terms, as well as many of the Apollo astronauts.

In April 2007, to mark the 50th anniversary of *The Sky At Night*, Patrick wrote a 'Guide to The Universe' for *Focus* readers. His top sight was the Crab Nebula. "It is not so spectacular as a total solar eclipse, or as lovely as Saturn, but its importance to astronomers cannot be overestimated," he wrote.

Patrick was always willing to contribute to the magazine if it would help promote his

favourite cause, even when the connection to astronomy was a tad tenuous. In 2010, when *Focus* was running an article looking at internet memes – phenomena that spread rapidly via the internet – Patrick agreed to appear in a video testing space-related snacks. Among the delicacies he tested on-screen was 'astronaut ice-cream.' "Mmm... disappointment," he said. "I can taste the ice cream all right, but it's not cold. It's rather chewy."

To date, the space snacks video has had over 40,500 views. Watch it for yourself at <http://bit.ly/Rn4cJj> ...and smile.



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INSPIRING LEARNING



INSIDE SCIENCE

ROBERT MATTHEWS

THERE WAS A time when I'd now be getting some winter Sun and doing a bit of skiing (and a lot of falling over) in the French Alps. Not any more. For the Matthews household, the Age of Austerity means not having had so much as a weekend away since last spring.

Apparently, even those who do manage to get away are making economies. A recent survey found that 40 per cent of Brits are cutting back on their tips at holiday resorts, which isn't entirely surprising. In these parlous times, who'd voluntarily spend another 10 or even 20 per cent on something whose price was probably already over the odds?

But then, tipping is one of those things that doesn't always make sense – at least, not economic sense. Sure, we like to give tips for a job well done to, say, babysitters, because we're keen to 'buy' their availability at weekends. But why do we tip London cabbies we're very unlikely ever to see again?

I've long been fascinated by the social phenomenon of tipping, and it seems I'm not alone. The subject is attracting growing scientific attention, with psychologists, sociologists and economists trying to untangle the various forces at work.

It's proving a big challenge. For a start, there's the huge cultural differences in tipping. Americans and Germans tend to tip pretty generously – 20 per cent is nothing special. While in Asian countries like Japan, tipping is actually deemed insulting.

Then there's the motivation.

The idea that tipping is simply a monetary expression of what we thought of the service seems to be nonsense: studies have found a poor correlation between the quality of service we get and the size of tip we leave.

As for the mystery of tipping at restaurants we're unlikely to visit again, various theories are currently doing the rounds. The simplest – and one that could explain why tips aren't closely tied to service – is guilt. People just feel awkward being served by others, and use tipping to compensate the other person for being in a subservient position.

Well, it's a nice theory, but it raises a whole lot more questions. Does it mean we should avoid people who don't tip, because they may be guilt-free psychopaths? And what about those nations that leave huge tips – are they neurotic basket-cases?

There's only one proper way to find out, and that's to turn to science. The analysis of data by scientific methods is renowned for giving us amusing but fundamentally useless insights into, say, the

You'd think this waiter wouldn't get a tip at all... but you'd be wrong



“Scientific methods have found that tipping rates are higher in countries with higher rates of neurosis”

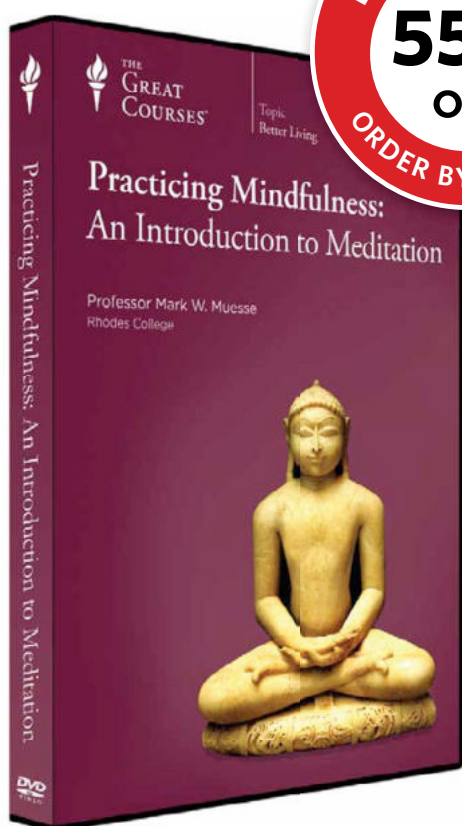
age of the Universe or the existence of the Higgs boson. But there's no reason why it can't also be applied to the tipping phenomenon.

It's still a pretty underexplored field, but a start has been made by a few pioneering researchers, notably Professor Michael Lynn at Cornell University. A former bartender and waiter, Lynn trained as a social psychologist and has used this to examine the effectiveness of alleged tip-boosting methods.

For example, by comparing data on tipping levels in 21 countries with surveys of national psychological traits, Prof Lynn has found that tipping rates are indeed higher in countries with higher rates of neurosis – like America. He's also looked at data on techniques to persuade customers to give bigger tips – and discovered that small things count for a lot. Writing 'Thank you' on the bill produces a small increase in tip size, as does drawing a smiley face (though only if you're a waitress; with waiters it comes across as a bit, well, weird). But anyone wanting a hefty tip should introduce themselves by name with a genuine smile.

Lynn is keen to hear from anyone interested in putting the various strategies to the test. It's a great idea for a mass experiment. Maybe those serving grumpy British tourists should give him a call. ■

ROBERT MATTHEWS is Visiting Reader in Science at Aston University, Birmingham



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HIDDEN TREASURES

HELEN CZERSKI

ICE IS ODD stuff, in all sorts of ways. But have you ever wondered about the appearance of this beautiful, sparkly, jewel-like version of water? It's transparent and apparently has no colour – basically, it's invisible. You can look through a perfect sheet of ice in the same way you look through a glass window. There's nothing to see. So here's a question: why can we see snow?

Just imagine how different our view of winter would be if snow looked see-through, while still behaving as a solid. A snowy winter wonderland would just look as though someone had varnished the outdoors a bit. You'd be able to see what every snowman had eaten for dinner (and whether someone had cheated with a bit of scaffolding to hold it up). And an igloo would have all the privacy of a greenhouse.

Snow is made of unimaginable numbers of tiny water crystals, frozen in the intricate shapes that we call snowflakes. Interestingly, all UK children draw perfect six-sided snowflakes, even though they've almost certainly never seen one. Because winters are relatively warm in the UK, our snowflakes are a bit wet and sticky and tend to clump together in fluffy-looking balls. So unless you are very lucky, or go to somewhere super-cold, you're unlikely to see the thing we think of as a snowflake falling from the sky. But that fact probably won't stop you drawing them with perfect six-sided symmetry...

Once all of those beautiful crystals are piled up on the ground, what you see is not the crystals themselves, but the effect they have on light. Ice has a different refractive index to air, which means that as light travels from air into ice, it changes direction a bit. The same happens on the way out. So when light hits snow, it's entering a really complicated kaleidoscope. Every time it goes through an ice-air boundary, it's redirected (and sometimes reflected completely). And in snow, with all those millions of intricate crystals, light is jostled about all over the place. Eventually, some of the light finds its way back

out of the snow. White light goes in, so white light comes out. And voilà... we can tell where the snow is because we see the light that has been on this journey.

The same physics governs the reason we can see clouds (water in air) and underwater bubbles (air in water), even though they are also made of invisible stuff inside other invisible stuff. And the two 'invisible' things can even be made of the same stuff. This isn't really the season for mirages, but hot air and cold air have different refractive indices. When a road makes air hot

“Snow is made of unimaginable numbers of water crystals. On the ground, what you see is not the crystals but the effect they have on light”



You'd have to endure very cold conditions to see classic snowflake patterns

by heating it up in the summer, we see the light being bent in funny ways as it goes from hot to cold and back again. The moving air boundaries make the scene behind shimmer as the currents of air shift.

A pristine winter wonderland looks pure precisely because the light isn't being sullied or changed in any way. It's just being diverted again and again until it happens to come back out. All those tiny diversions make the invisible visible, and hide whatever is underneath. The snowman's secret is safe, at least until the water melts. But when the Sun comes out and solid turns to liquid, the liquid will fill up all the air gaps and so the boundaries will disappear.

And once the method of disguise is removed, we're sorry Mr Snowman, but we can see right through you. ■

DR HELEN CZERSKI is a physicist, oceanographer and BBC science presenter whose shows include *Operation Iceberg* and *Orbit*

QUESTIONS AT THE FRONTIERS OF...

VIROLOGY

Some viruses cause disease, while others have health benefits. They're everywhere and yet we still don't know enough about them, says **Vincent Racaniello**

Q Why is there no vaccine for HIV?

SINCE HUMAN IMMUNODEFICIENCY virus (HIV) was identified as the cause of acquired immunodeficiency syndrome (AIDS) in 1983, the disease has killed 30 million people, and today 34 million live with the disease. A vaccine might help end this pandemic. But after 30 years of research, one is not yet available.

Current vaccines to prevent polio and measles work by prompting our immune system to produce antibodies – large proteins that combine with virus particles and render them unable to infect cells. Before these vaccines were developed, researchers studied individuals who'd recovered from infections, and knew that antibodies would be important for protection.

Unfortunately we have no such information about AIDS patients: we aren't aware of anyone who has cleared HIV from their body by an immune reaction, so we haven't been able to identify natural immune responses that a vaccine could elicit to prepare the body for infection by the virus. Several other complications have also confounded vaccine design, such as the fact that HIV can undergo stupendous levels of genetic variation to escape the immune response, and that the virus destroys the immune system itself.

Various vaccine candidates have been tested in humans, but all have failed to protect people from AIDS. In a 2009 trial in Thailand, patients given a vaccine had a 31 per cent lower rate of infection than those who'd received a placebo, but this protection rate is too low for a licensed medicine. Another boost in the quest for a vaccine was recently provided by the identification of human antibodies that

can neutralise infection by nearly every strain of HIV that was tested. If a vaccine were designed to induce the production of such antibodies, it could conceivably block the replication of any variant of HIV – overcoming a major obstacle to creating an effective vaccine.

Figuring out how to elicit these antibodies in humans will be the key to developing a vaccine, but it's also a formidable challenge because such antibodies are rare in infected humans. Many years of research on HIV have provided excellent experimental systems and animal models that will help move this promising concept rapidly into human clinical trials.

Q Are viruses good for us?

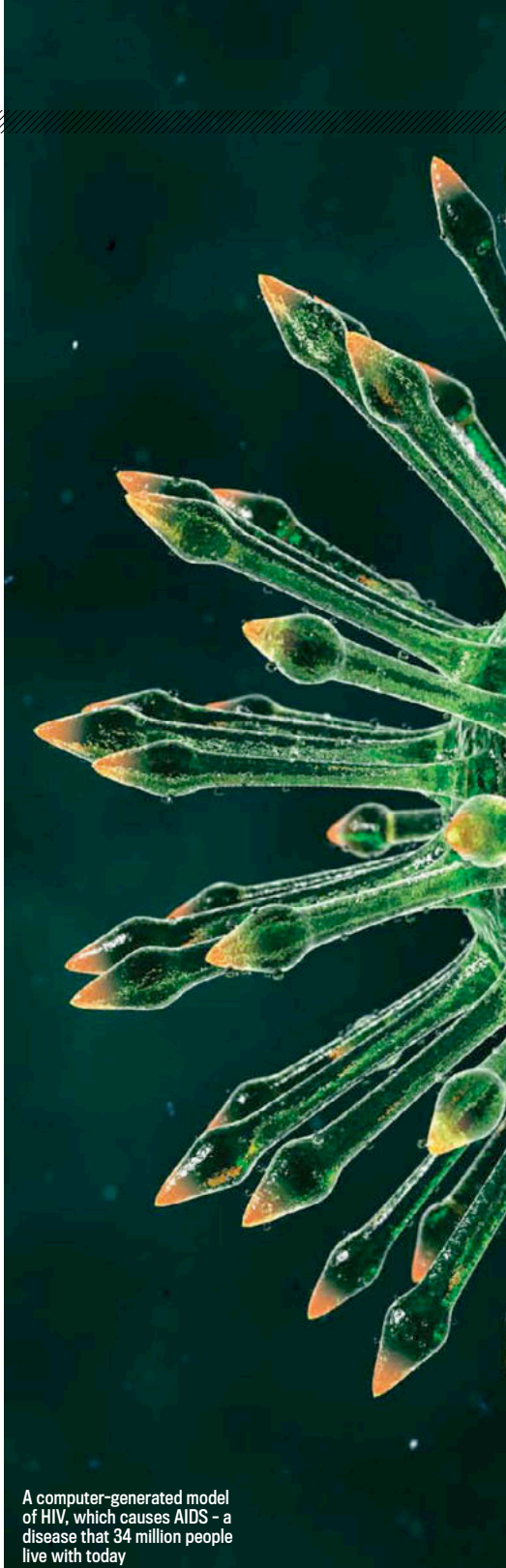
With frequent reports of killer viruses in the news, why would we think they might be good for our health? The idea stems from our symbiotic relationship with other microbes: the 100 trillion bacteria in the human body provide useful functions in exchange for food and a place to live. Our gut flora, for instance, helps our immune system develop, provides vitamins, and prevents the growth of pathogenic bacteria.

The idea of 'friendly viruses' is supported by experiments where mice were infected with latent herpesviruses. During childhood, all humans become infected with several herpesviruses: after initial infection, the viruses become dormant – 'latent' – and get reactivated by certain cues. A cold sore, for example, emerges after stress awakens a latent herpes simplex virus.

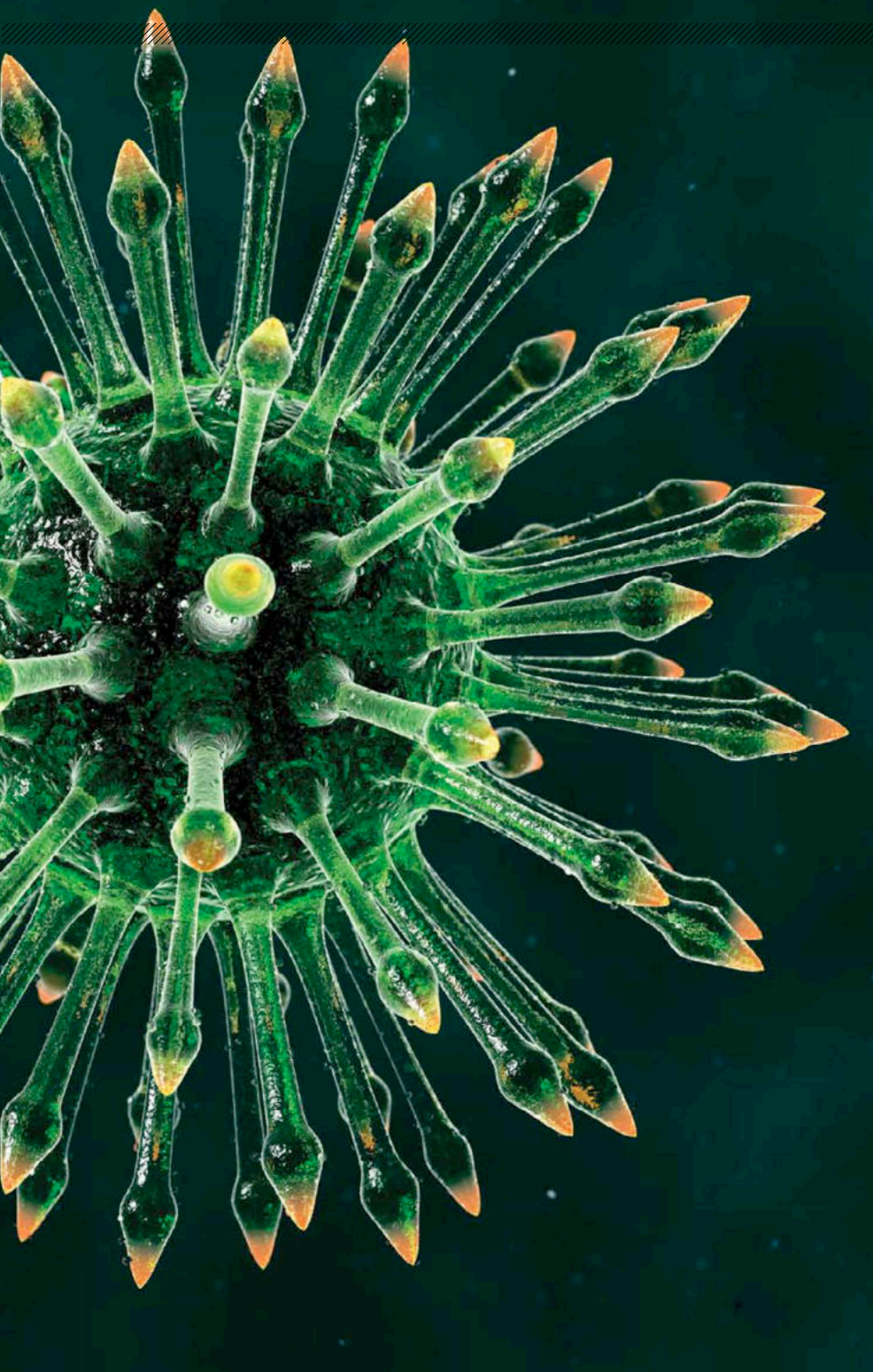
In the mouse experiment, infection by latent herpesviruses induced an innate immune response that enabled the animals to become resistant to the bacterial

pathogens *Listeria monocytogenes* and *Yersinia pestis* – the causative agents of listeriosis and plague. Before this study, herpesvirus latency was considered to be a pathogenic state, but it now seems that it could be a symbiotic relationship with an advantage for the host.

There are other examples of beneficial virus infections, including a retrovirus of sheep that helps the placenta develop. Many such examples come from animals,



A computer-generated model of HIV, which causes AIDS – a disease that 34 million people live with today



which we can infect to study the consequences – an approach that isn't permitted with humans. To determine whether a human herpesvirus prevents infections by other pathogens, for instance, we're limited to observation and correlation. Few are free of herpesviruses, unfortunately, making it difficult to evaluate the effect of the viruses on other infections.

Other human viruses aren't as ubiquitous and could be used to study whether their

presence correlates with protection against diverse pathogens. Once we determine all the viruses present in humans, we can begin to establish how certain viruses might affect immune functions and, in turn, resistance to other infections.



How many viruses are there?

About 3,000 viruses have been identified

so far, but this is probably only a fraction of the total number. If we assume there are 50,000 vertebrate species on Earth, and each harbours 20 different viruses, that gives a total of 1 million viruses *in vertebrates alone*. Therefore, over 99.7 per cent of vertebrate viruses have not yet been discovered!

Knowing the number of viruses sounds like a bean-counting problem, but understanding viral diversity has health benefits: all new human viruses emerge from an animal host, for example, so it helps to be aware which hosts could harbour potential pathogens. We're wary of avian influenza carried by birds, so should we watch out for other animal species?

Viruses also play a key role in evolution: they shuffle genes around by transporting them from one organism to another, and move genetic material within a host's DNA. Knowing more about all viral genes out there can have practical benefits too: we could exploit viruses to remove pollutants from the environment, and engineers are now using viruses to build better batteries.

So where do we look to find all the viruses on Earth? One study has sampled viral genomes – 'viromes' – from the Arctic Ocean, Sargasso Sea, and the coastal waters of British Columbia and Gulf of Mexico. Comparing these viromes revealed that over 90 per cent of DNA sequences had never been seen before. Such sampling has mainly been of surface waters – there are surely more viruses deeper down, in freshwater, and inside aquatic hosts.


Other sources of viral diversity include the air, the Earth's crust, and the various life forms on the surface. No-one knows, for instance, which viruses are carried by all our cats, dogs and mice – the species most familiar to us. We don't even know how many viruses a healthy human lives with on a daily basis, let alone how this number changes over our lifetime.

However, the problem of counting all the viruses on Earth isn't as difficult as it might seem. Our planet is large, but the diversity of hosts is limited, and we've developed powerful technologies to identify viruses in clinical and environmental samples. Our progress is limited only by the amount of money we invest in such a venture. While exploring outer space appeals to many, the viral universe here on Earth has been barely visited. ■

Professor Vincent
Racaniello is a virologist
at Columbia University
and runs a blog at
www.virology.ws



WONDER OF LIFE

A wireframe bird, possibly a pigeon, is shown in flight, facing left. The bird is composed of a green and blue grid of lines, giving it a digital or scientific appearance. It is positioned on the left side of the page, partially overlapping the large title text. The background is a dark blue and purple gradient with a faint, glowing grid pattern.

With Brian Cox's new BBC series set to hit the screen, **Professor Matthew Cobb** looks at how one of life's greatest wonders, the senses, evolved – and how they could be transformed in the future ➔

RS





OVER THREE AND a half billion years ago, there was a population of cells from which all of life has descended. To survive, those organisms had to detect gradients of energy, salts and foods in the difficult conditions of the primeval ocean. Today, all living things carry the legacy of those earliest attempts to respond to the environment, in the form of our senses. It's a fascinating story brought to us by Prof Brian Cox in his ground-breaking new BBC series *Wonders Of Life*.

We now have a better understanding than ever of how our senses evolved and how they work. And although there are surprising gaps in our knowledge, this understanding is helping us to repair our senses when they get damaged – and in the future may even allow us to enhance them.

In every animal sense, cells represent an external signal in terms of an altered internal state. The basic mechanism, which is shared by virtually every organism with a cell nucleus, involves the movement of charged atoms and molecules – known as ions – through pores or 'channels' in the cell membrane, which can be open or closed. The movement of ions leads to a difference in electrical charge between the inside of the cell and the external environment. It's a change that allows the organism to react.

This is the mechanism that enables us to see, hear, smell and touch and therefore allows our complex behaviour. But the way this occurs in your cells is the same as in the single-cell organism, the paramecium, even though it's a primitive creature – a living insight into what life must have been like a billion years ago.

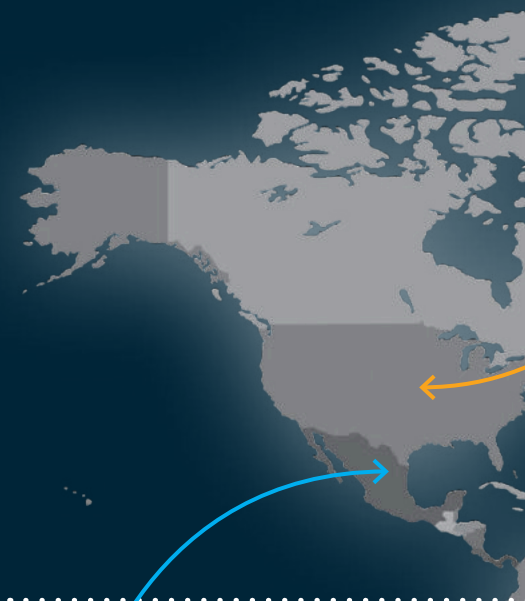
LIVING RELIC

The humble paramecium moves forward by waving thousands of tiny cilia, or hairs, that cover its body. When it bumps into something, it reverses and moves away, by changing the way the cilia beat. The paramecium's sense of touch is extremely simple: when it pushes against an object, its outer membrane is deformed, leading to the opening of calcium channels, which allows calcium ions to flood into the cell. These trigger a change in the electric field inside the cell, altering the direction the cilia wave, allowing the paramecium to move away. The calcium ion channels then close and potassium channels open, allowing potassium ions to leave the cell. This restores the slightly negative charge, and the paramecium moves forward again.

Once life had evolved this simple way of changing its cellular physiology in response to the outside world, the way was open to develop specialised and precise senses. The first senses will have involved responses to the key challenges faced by the earliest life. Those included

WORLD OF WONDER

Locations visited by Brian Cox during the making of *Wonders Of Life*



EPISODE 4 HOME

LOCATION: MEXICO

The story of how our planet has become a rich, life-supporting world – the only one we currently know about in the entire cosmos – is told in this episode. Brian swims through the flooded caves, or 'cenotes', of Mexico's Yucatán Peninsula to look at how vitally important water is to the many forms of life on our planet.



The paramecium is one of the most primitive surviving creatures

EPISODE 1 EXPANDING UNIVERSE

LOCATION: USA

Brian travels across the USA to learn how the suite of senses we see in the animal kingdom evolved, and finds some species have developed some surprising sensory adaptations. The ferocious catfish he encounters in the Big Black River, for instance, has 'taste' sensors over its entire body.



EPISODE 2 WHAT IS LIFE?

LOCATION: RING OF FIRE, SOUTHEAST ASIA

The very beginnings of life on Earth are considered in this episode. At the Taal Volcano in the Philippines, the caldera of which is partially filled by a lake, we see how energy bubbles up to the surface from the Earth's innards, creating conditions similar to those that led to the first spark of life.



EPISODE 5 ENDLESS FORMS MOST BEAUTIFUL

LOCATION: MADAGASCAR AND SOUTH AFRICA

There are over 100 million species alive today. Why is there such a rich diversity of life? To find out, Brian visits Madagascar, a biodiversity hotspot. Here he encounters the aye-aye, a species of lemur, which taps on trees to find grubs and uses a slender middle finger to prise them out.

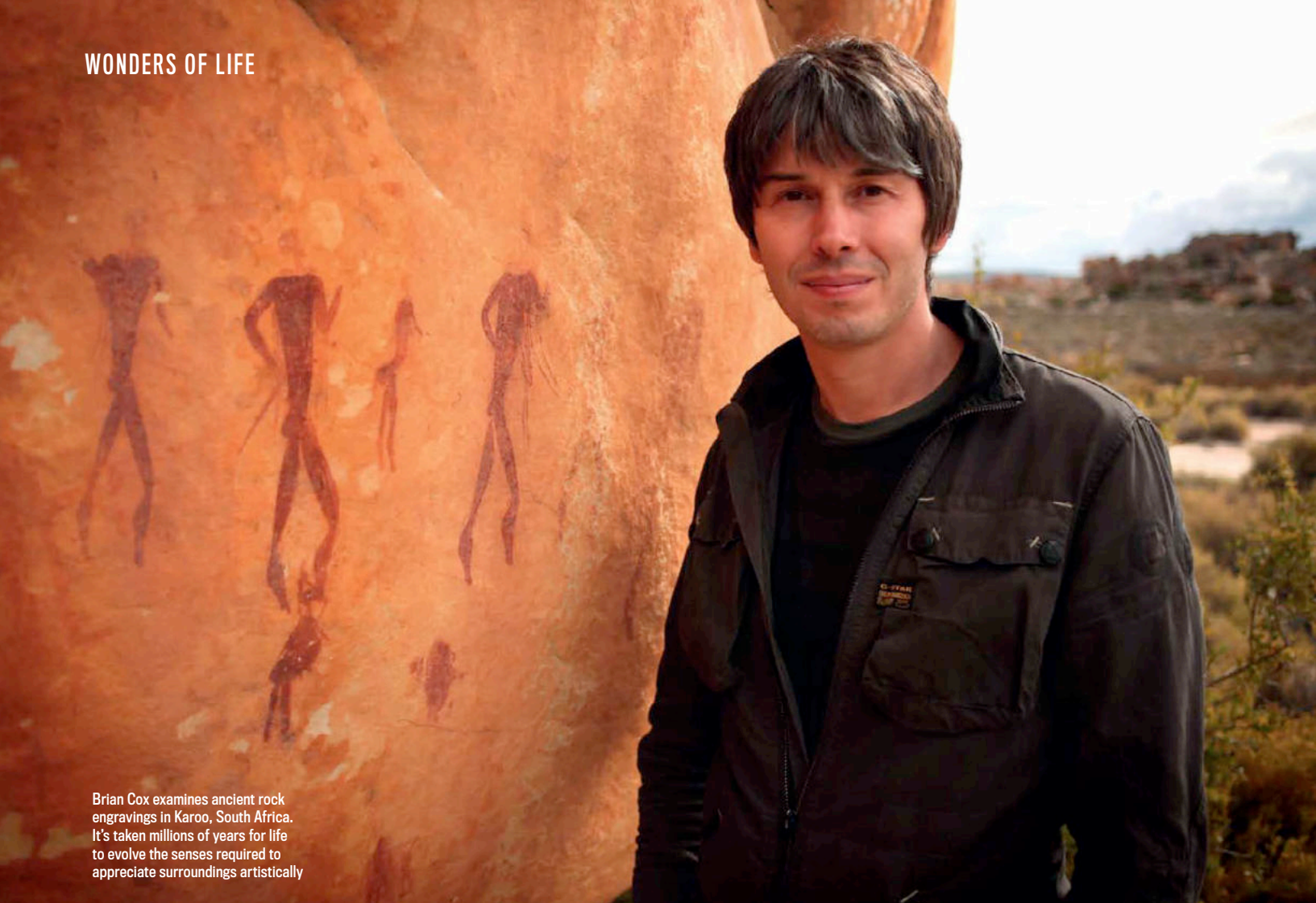


EPISODE 3 SIZE MATTERS

LOCATION: AUSTRALIA

From 110m-tall trees to single bacteria less than a millionth of a millimetre long, life comes in a huge range of sizes. Brian looks at how forces such as gravity and electromagnetism have different effects along this scale. While shark diving off the Neptune Islands, he explores why Earth's biggest animals are in the oceans.





Brian Cox examines ancient rock engravings in Karoo, South Africa. It's taken millions of years for life to evolve the senses required to appreciate surroundings artistically

→ finding chemicals that indicated a food source, or avoiding chemicals that marked dangerous environmental conditions. These early organisms would have navigated like modern-day bacteria, moving up and down chemical gradients (different concentrations of particles).

HEARING BONES

From here, the course that evolution took in shaping the senses depended on the ecology of the ever-growing number of species (see 'Supersense specialisms', p39). An organism's ecology is the environment it lives in, as well as the other species with which it interacts – competitors, predators and prey. All these aspects of ecology affect the senses that a species evolves and therefore how the world appears to them.

The predatory giant flathead catfish is a perfect example of how ecology and evolution have shaped the senses. It lives in the muddy waters of the Mississippi in the US, where visibility is near zero. The catfish retains its eyes, although they are very small. So to capture its prey it relies on several other senses.

Key to the catfish's sensing system is the giant chemosensory organ that is the outside of its body. It has no scales –

“Natural selection doesn't create structures from nothing - it slowly shapes them from existing features”

instead it is covered with 'taste' receptors that allow it to detect changes in the concentration and quality of thousands of different molecules that float through the water. Living in a muddy world, the catfish constructs a four-dimensional chemical image of the river, using taste and smell to identify locations. Catfish use their complex array of sensors to remember that certain chemicals are associated with food.

In common with many other terrestrial vertebrates, vision and hearing are the main senses that humans use to orient ourselves in the world. In our case, these are also the senses we use to communicate.

Hearing is simply the detection of changes in pressure. Tiny hairs in our inner ear – the spiral-shaped cochlea – are moved about by vibrations in the fluid that they bathe in. As they move, the hairs activate ion channels in nerve cells. These form action potentials, a change on the surface of a cell that results in an electrical impulse being sent via the auditory nerve to the brain. But for the vibrations to get to your cochlea, they first have to travel down a trio of tiny bones.

Sound from outside first hits your eardrum, which then transmits the vibrations through three bones – the malleus, the incus and the stapes – and finally into the fluid in your cochlea. This occurs in an extremely efficient way. Around 60 per cent of the sound energy from the air is transmitted into the cochlear fluid, meaning that of all the vertebrates, mammals have the most efficient ears.

Amazingly, those three bones are the remnants of the skull bones of our vertebrate ancestors. Around 230 million years ago, our ancestors changed the way their lower jaw articulated with the back of the skull. For decades, the sequence of events remained obscure, but in 2011 an exquisite 120 million-year-old fossil was discovered in China that

SUPERSENSE SPECIALISMS

Evolution has led different species to detect the world in very different ways



Mosquito

They have been on this Earth for perhaps 200 million years, honing a battery of sensors that now allow them to seek out new mammalian prey so they can suck their blood. Mosquitoes can detect carbon dioxide exhaled nearly 40m away, using specialised nerve cells sticking out from their mouthparts. Body heat is detected by thermal receptors and there's even a specialised sensor that can pick up the odour of sweaty feet.



Kestrel

Raptors' incredibly sensitive eyes enable them to spot their rodent prey. They have twice the density of receptors found in a human retina. Using head tracking to keep the eyes stable while the body moves, raptors can detect minute movements of prey dozens of metres below. With four different rhodopsins in their eyes, kestrels can see the ultraviolet light reflected off the scent trails with which rodents mark their territory.



Star-nosed mole

This bizarre, completely blind little mammal lives underground in eastern Canada and the northeastern USA. Its snout is covered with 22 fleshy appendages that are touch organs, enabling it to navigate in the darkness. Each of these 'tentacles' has over 10,000 touch receptor cells that enable it to identify and eat prey in less than 150 milliseconds. Each 'tentacle' has a corresponding area in the animal's brain.



Pit viper

These snakes have two unique heat-detecting organs in their heads. These 'pit organs' enable the viper to detect its warm-blooded prey – and because they are at the front of the head, slightly apart, the viper can discern the size and direction of its victim. This allows these snakes, which live in Asia and North and South America, to hunt in the dark, lying in wait for their victims and suddenly ambushing them.

provided answers. In this small mammal, *Liaconodon hui*, the three inner ear bones were still attached to the jaw, while the eardrum was anchored to the skull, providing a primitive hearing system. The final separation of the three ear bones was a way of making hearing even more acute.

The first step was that two bones that were no longer employed as a jaw hinge shrank in size and moved into the skull, becoming the malleus and the incus. With this improved hearing system, the mammals could detect the high-pitch noises of insects and perhaps capture them more easily as a result. Although this bone arrangement is found in all mammals, we know it evolved twice – once in the monotremes (echidnas and platypuses) and once in the ancestor of the placental mammals and the marsupials.

The evolution of the mammalian ear is a great example of how evolution does not design, it tinkers. Natural selection doesn't create structures from nothing – it slowly shapes them from existing features. At every step of the way, there is

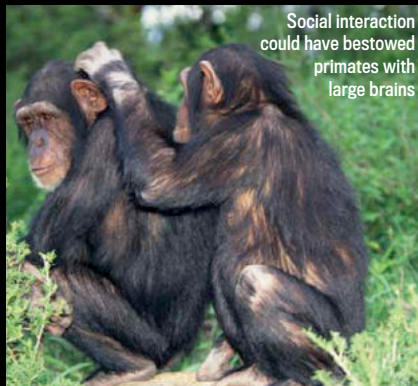


Liaconodon hui, discovered in 2011, provides a clue as to how our hearing evolved



BIG EYES AND BIG BRAINS

Did good eyesight lead to our intelligence?



Social interaction could have bestowed primates with large brains

When the earliest primates appeared – which happened shortly before the disappearance of all the dinosaurs except the birds – they were probably nocturnal. Equipped with large eyes packed with millions of receptors, their optic nerves fed into their brains and drove the growth of the visual processing areas of the brain. Now, 65 million years later, one of the descendants of those earliest primates (namely us) dominates the planet and has a massive brain that is capable of thought, language and abstract concept manipulation. Our close primate relatives are also highly intelligent.

Some scientists have argued that this apparent sensory preference for vision has been the decisive factor in the growth of the primate brain. According to this theory, the fact that some species, including humans, have developed stereoscopic and trichromatic colour vision – with three different types of colour receptor – may be the ultimate explanation of our intelligence, as the brain requires a large number of neurones to process all this information. Many mammals are highly visual species, yet only primates have achieved brain development on such a scale.

It's actually the intensely social existence of primates that's most likely to be behind our big brains. A social lifestyle requires an animal to recognise and process subtle and multi-sensory signals involved in communicating status and interactions – everything from facial expressions to pheromones.

Ultimately, a definitive answer to the question of why our brains grew so big will be difficult to find because we cannot easily do an experiment. But genetics may provide clues. If we can figure out whether genes associated with the growth of parts of the brain show signs of having evolved in parallel with genes involved in vision or social behaviour, it could settle the argument.



The sharp-sighted mantis shrimp can see ultraviolet wavelengths, through to our visual range and all the way into the infrared

→ some kind of selective advantage to be gained by making a small change. Eventually, over evolutionary time, the continued action of natural selection sculpts organisms so that it looks like they have been 'designed'. In fact, they're merely the product of hundreds of thousands of generations of selection. So sometimes the result is far from perfect.

BAD DESIGN

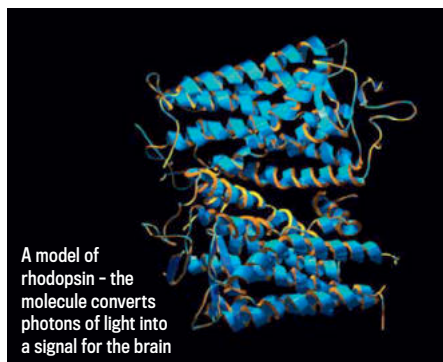
This is strikingly true when it comes to the eye. Eyes have evolved separately and repeatedly in animals many times over – perhaps 40 times in the last 700 million years. So although our eye and the eye of the octopus are both complex camera-like eyes, they are not related – they were 'invented' separately, at different times.

Each time, a particular set of light-sensitive molecules called rhodopsins has been employed to turn particles of light, or photons, into a change in the activity of a cell. This pigment, also known as visual purple, is found across the animal kingdom, from fruit flies to humans. It's the point where physics meets biology,

changing in shape when struck by a photon and initiating a cascade of action potentials. Different rhodopsins respond in this way to different wavelengths of light, enabling an animal to respond to a range of visual stimuli.

Although we still do not know exactly when vision evolved, the fact that no sponges have yet been found to carry genes for rhodopsins implies that vision appeared after sponges split off from the rest of the animal kingdom, over 700 million years ago. As the genomes of more and more species are sequenced, researchers are now exploring the evolution of rhodopsin genes in all animals.

Natural selection gave an advantage to any animal that could detect even small amounts of light, and eyes rapidly evolved from photosensitive patches into the complex camera eyes you are using now. Amazingly, despite the fact that eyes differ so much and have evolved so many times, in most animals the same gene, *pax6*, is involved in telling the body how, where and when to grow an eye. It does this by controlling the expression of other genes – the protein it produces binds to DNA



A model of rhodopsin - the molecule converts photons of light into a signal for the brain



Brian Cox examines the local flora on location in Madagascar

during development. This 'transcription factor' acts as a master control gene. It determines whole cascades of protein production, deciding where and when those proteins are produced.

But despite its beauty, the incredibly sophisticated human eye is a classic example of evolutionary bad design. The receptor molecules are hidden away at the back of the retina. Light has to pass through a tangled network of membranes and cells before it can get to the decisive component – the rhodopsin molecule. It doesn't have to be this way – the eye of the octopus is wired the other way round. It's simply a consequence of the evolutionary route our eyes have taken.

Perhaps the most amazing example of visual acuity is the mantis shrimp, which despite its name is not actually a mantis nor even a shrimp. It has the most advanced visual system in the animal kingdom, and possesses no fewer than 16 visual pigments in its compound eyes. We have to get along with a mere four. This allows the mantis shrimp to see at least 12 different wavelengths of light, from deep in the ultraviolet part of the spectrum,

“Eyes have evolved separately and repeatedly many times over - perhaps 40 times in the last 700 million years”

right across our visual range and into the infrared. It's also able to determine the angle at which these waves are moving as they travel through space.

The mantis shrimp also has trinocular vision – each point in space can be detected by three different parts of each of its eyes, which can be moved independently. This gives it incredibly precise depth perception, just as you can see depth because your eyes are slightly separated. This highly accurate depth

perception, coupled with near 360° vision, makes the mantis shrimps' eyes ideal for tracking and killing prey.

ARTIFICIAL EVOLUTION

While humans senses are often some way off the peak of evolutionary engineering, we're now developing tools that could give us the ability to enhance them. One of the clearest signs of this came back in 2007, when Prof Gerald Jacobs at the University of California in Santa Barbara inserted a piece of DNA that codes for a human eye pigment into the genome of mice. With their extra pigment, the mice could see extra colours – their brains were able to process data they didn't normally receive. It sounds like science fiction, but one day it may be possible to add DNA from, say, a mantis shrimp to the human genetic code to enhance our colour repertoire – perhaps even giving us the ability to see ultraviolet light.

Our hearing could be enhanced too. Underwater, divers can detect sounds of up to 100kHz. Out of water, the upper end of ability is nearer 20kHz. Experiments carried out in 2011 by Dr Michael Qin at the Naval Submarine Medical Research Laboratory in Connecticut suggested that this enhanced hearing ability may be because underwater, sounds travel directly through the bones of the inner ear and then into the cochlea, without passing through the eardrum. Mimicking this more direct stimulation of the bones when we're out of water could enhance our hearing range.

These are exciting times. Technology is helping us see the world as never before, and in the near future could transform our sensing abilities. Whether we *want* to artificially evolve and develop our own supersenses is a question we may have to confront in the next few decades. ■

MATTHEW COBB is Professor of Zoology at the University of Manchester and was a scientific advisor on *Wonders Of Life*

Find out more



Wonders Of Life will be screened on BBC Two in early 2013

Life Ascending: The Ten Great Inventions Of Evolution by Nick Lane (Profile Books, 2010)

What Is Life? by Erwin Schrödinger (Cambridge University Press, 2012)

INTERVIEW BRIAN COX

The scientist and BBC presenter talks about a close encounter with an alien intelligence and why physics rules the living world



PHOTO: IAN DERRY

Most people know you as a physicist. Have you abandoned physics with *Wonders Of Life*?

No. The idea of the series was to look at life, if not from a physicist's perspective, then from a deeply scientific perspective.

Was there an animal you filmed that particularly intrigued you?

I dived with an octopus in Florida when we were filming the programme about the senses and that was fascinating. If you look for a common ancestor between us and them, it was 600 million years ago. It's a long way back. At that time there were no brains, no eyes, no nervous systems. The idea of the film is that you can make a case that the evolution of intelligence has fed off and paralleled the evolution of the senses. One of the strong ideas for the emergence of intelligence is that vision requires a lot of processing power. So the better your sight is, the more sophisticated your brain has to be to deal with all that data. Octopuses are a beautiful example because they are very clever animals – their intelligence has evolved separately from ours. If you are looking for an alien intelligence, then an octopus is probably it.



Octopuses mimic you, and I ended up having a little boxing match with the one we saw. I put one of my fists up and it reared up on six of its legs and put its two other legs up, copying my fists. A member of the film crew went and got a tattoo of the octopus because he got so attached to it.

How does physics help us make sense of why life is so diverse?

One of the programmes looks at size. On land, you ask what are the constraints on the size of animals? Obviously, to some extent, it's driven by gravity but it's also influenced by things like the cross-sectional area of bones. Bones have got to increase in cross-sectional

“One of the key ideas of the series is that evolution doesn't really have a free hand - it's constrained by the laws of physics”

area significantly as the animal gets more massive. The constraints on the strength of the skeleton change as you get bigger and that's one of the reasons you don't get enormous land animals. Another reason is the way surface area changes in relation to volume – large animals tend to overheat because they can't get the heat out.

If you go into the water, then things are effectively weightless – so gravity doesn't make any difference at all. We look at the physics of all this. One of the key ideas of the series is that evolution doesn't really have a free hand – it's constrained by the laws of physics.

Physics rules, in other words...

Well, yeah, obviously it has to because these are universal laws that apply to inanimate and animate objects.

Do you think there's life on other planets?

Yes. People are beginning to think that we will find evidence that there was life on Mars. There is strong evidence of subsurface water there and water appears to be essential for life. We ask why that is, and it's because it's got some properties which are absolutely fascinating. I came to the view with the advisors on the series that if you have the right conditions – water, some organic compounds, a bit of rock and some pH gradients – then life will appear spontaneously. So you might look at Europa, too, with its oceans and its vents.

What about intelligent life outside our own Solar System?

We touch on this in the series too. The thing is, there are certain things that

took place on Earth that look like they were chance events. A critical one is the emergence of what's called the eukaryotic cell, which is a cell with a nucleus. That was down to a process called endosymbiosis, where two single-celled organisms – probably a bacterium and an archaea – fused together. So one got inside the other one and it didn't die, so you got this symbiotic existence. Now that's what we are. Every cell in our bodies is essentially the remains of a symbiont. That fusion took place once – we know that. Once. And it took well over a billion years for it to happen and without that, you won't get complex life.

So there is a big distinction between single-celled organisms and complex life. Complex life's development on another planet looks really unlikely, although we have got a statistical sample of one. So we don't know. But it took a long time for it to happen on Earth.

Did any of your encounters with life here on Earth get too close for comfort?

I suppose the most superficially scary encounter was when we filmed in a cage with great white sharks off the coast of Australia. But actually I didn't find it all that scary, because I was in a cage. Sharks tend to be portrayed as these mindless killing machines, but it didn't feel like that at all: they were just these graceful objects that swept around the cage. I said to the dive master, “It's almost like you don't need a cage.”

But he said: “If you were walking past a cake shop with no glass in the window, might you not be tempted to reach in and eat a cake? It's a bit like that...” ■

PLAYING FIRE

Geoff Mackley/Caters News

WITH

How one man risked extreme temperatures, noxious gas and lava bombs to get closer to a volcano than anyone has been before.

Paul Sutherland investigates

THIS IS THE dramatic moment one man achieved his burning ambition – to get up close and personal with a volcano. Geoff Mackley, a freelance photographer and film-maker, had climbed deep into the jaws of an active crater as magma bubbled away beneath him at over 1,000°C.

The adventurer donned a heat-resistant suit and breathing apparatus to stand just 30m away from the molten rock. It was the culmination of a 15-year effort to get closer than anyone has ever been before to the lava lake inside the Marum volcanic cone on the island of Ambrym. Located on the Vanuatu archipelago, the island is part of the so-called Ring of Fire – active volcanoes that run round the edge of the Pacific, marking the point where shifting tectonic plates meet. ➔

Adventurer Geoff Mackley stands on a ledge above the fiery lake of lava inside Marum volcano. He wears a suit like a fireman's but risks 'bombs' of molten rock and the collapse of the crater walls.

VOLCANOES



Geoff and his support team, cameraman Brad Ambrose and assistant Nathan Berg, had made several attempts to reach Ambrym's inhospitable peak. This time they endured volcanic fumes and acidic rain for nearly two months as Geoff awaited the right moment to descend into the pit of hell.

The New Zealander spent \$80,000 (£50,000) on the latest trip, including a helicopter to carry his team and their equipment to the summit. When the ideal day came in August, Geoff first had to lower himself by ropes 400m down a sheer, jagged edge wall inside the crater to a ledge of black volcanic ash. As he braved the heat, part of the opposite wall fell away.

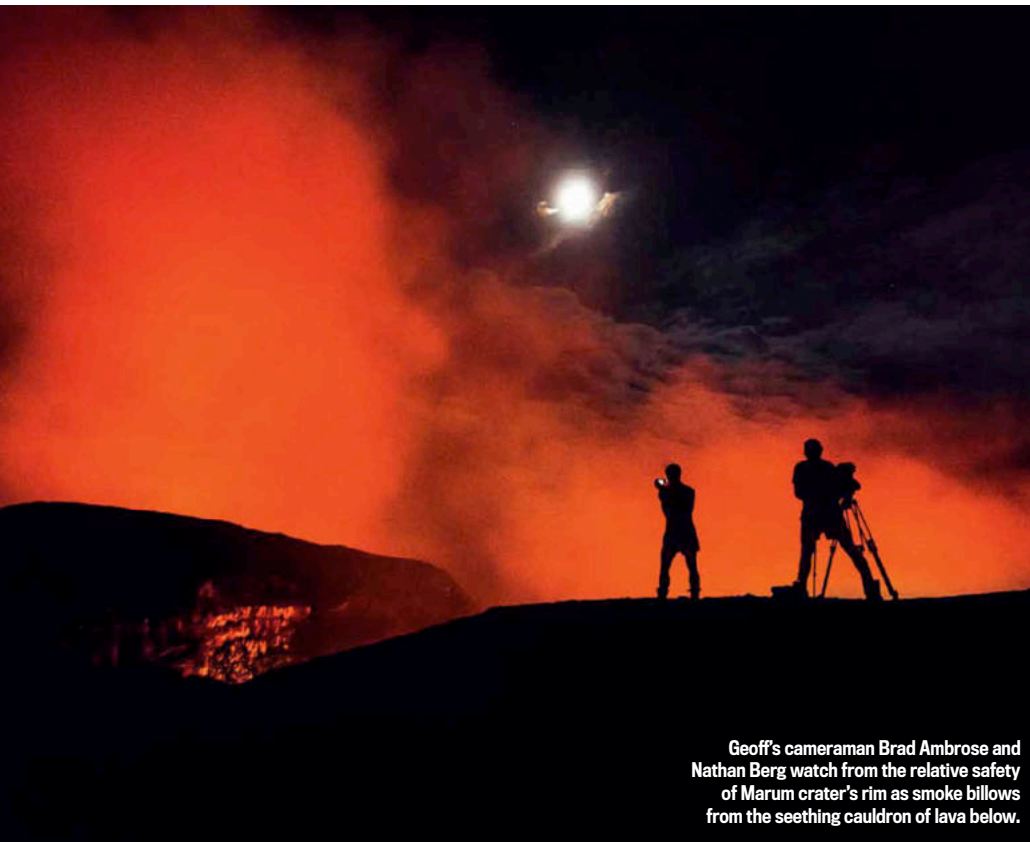
"Volcanoes are dangerous places to be. Climbing down one is extremely difficult, as the walls would be extremely brittle," says volcanologist John Murray of the Open University. "There is a lot of hydrothermal activity around a volcano where acid gases gradually eat away the rock. It means the inside of a crater can become very crumbly. You also get toxic or suffocating gases collecting in hollows. People on Hawaii have drowned in pockets of carbon dioxide. A big danger would be the 'bombs' of hot rock flying around. At any volcano I know, you get bombs flying out much further than 30m."

We can be thankful that Mackley made it out of the crater unscathed – the pictures are undeniably spectacular, revealing the bubbling cauldron of power that is an active volcano. ■

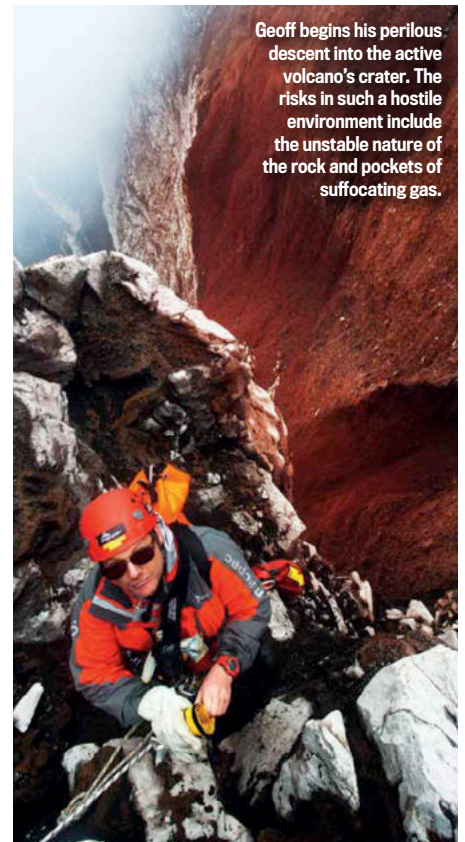


Clad in a heat suit with breathing apparatus, Geoff lowers himself on ropes towards a ledge just metres from the boiling magma mix, where he could be hit by flying bombs of hot rock.

Geoff Mackley/Caters News X4



Geoff's cameraman Brad Ambrose and Nathan Berg watch from the relative safety of Marum crater's rim as smoke billows from the seething cauldron of lava below.



Geoff begins his perilous descent into the active volcano's crater. The risks in such a hostile environment include the unstable nature of the rock and pockets of suffocating gas.

The lava lake below glows as Geoff makes his final climb down the crater wall. His heatproof suit, including a tank of compressed air, enables him to spend up to 45 minutes close to the churning mass of molten rock.



READ MOORE

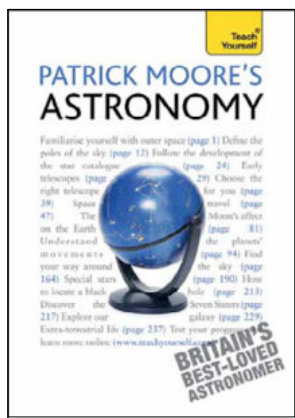
A selection of works from the iconic British astronomer



PHOTO: BBC

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The images present the Universe's extraordinary beauty as seen through the biggest and best telescopes on Earth and in space.

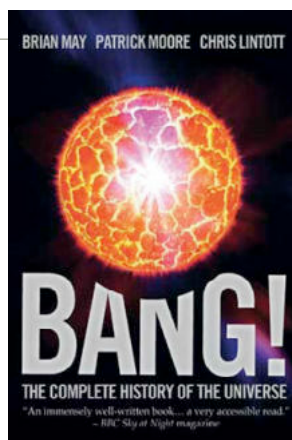


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The Universe was born 13.7 billion years ago. Infinitely small at first, Brian May, Sir Patrick Moore and Chris Lintott explain its expansion, from the moment when time and space came into existence, to the formation of the first stars, galaxies and planets, and to the evolution of humans. Then on towards the infinite future, long after the Earth has been consumed by the red giant Sun...

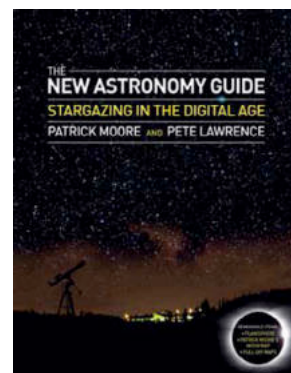


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THE MEASUREMENT OF ALL THINGS

From a ruler that can measure the width of an atom to the clock that's accurate to one-642,121,496,772,646th of a second, **Michael Banks** investigates the world's ultimate precision instruments →

THE ULTIMATE CLOCK

It's time for the next generation of super-accurate atomic time-pieces

IMAGINE A CLOCK so accurate that if it had been switched on when the Universe was born 13.7 billion years ago it would only have lost one second by today. That is what the latest gold-standard timepieces, called optical atomic clocks, will soon be able to achieve.

In today's atomic clocks – the world's official timekeepers – charged atoms, or ions, float in a 'trap' and are held in place by electromagnetic fields. They are then subjected to a beam of light that causes electrons in the ions to jump from a lower to a higher energy state. This

jumping takes place at a regular rate and acts as the atomic clock's 'tick'. The higher the frequency of the ticks, the more accurately time intervals can be measured. The UK's official time is currently measured at the National Physical Laboratory (NPL) in Middlesex using caesium-133 atoms, whose electrons jump an incredible 9,192,631,770 times a second.

But physicists are currently looking at a number of different atoms that would allow the clock to 'tick' even more frequently. At NPL, scientists are putting ytterbium ions – already

used in portable X-ray machines – through their paces, zapping them with lasers in ion traps. The signs are good. Research published in 2012 by NPL showed that a ytterbium ion clock would tick 642,121,496,772.646 times per second – a tick rate nearly five orders of magnitude higher than caesium. "Optical clocks are set to become the ultimate in timekeeping," says Professor Patrick Gill at NPL.

Satellite navigation uses atomic clocks, so more capable timepieces would make these systems even more accurate. Their sensitivity to outside influences could also be put to good use. For instance, portable optical clocks could be used to search for natural resources. As they are moved around, their tick rate would vary slightly in response to small changes in Earth's gravity, which could be caused by variations in rock porosity – a key way to find oil.

STRANGE BUT TRUE

On 30 June 2012, a 'leap second' was added to the official time measured by atomic clocks to account for the fact that the Earth's rotation had slowed a little. This meant that solar time – determined by our planet's rotation – was in danger of getting out of sync with the official time.

This optical atomic clock at the National Physical Laboratory in Middlesex 'ticks' 9,192,631,770 times a second

This watt balance, based at Canada's National Research Council, determines the weight of a kilogram by measuring it against the strength of an electric current

THE ULTIMATE **WEIGHING SCALES**

A balance that's 5,000,000 times more accurate than your bathroom scales

IN A VAULT at the International Bureau of Weights and Measures in Sèvres, France, is a cylinder of platinum-iridium alloy. This lump of metal, known as Le Grand K, is the official kilogram – its weight defines 1kg and it's used to calibrate scales around the world. The trouble is, its weight is changing relative to identical cylinders of the alloy kept at other sites around the world – which is not what a fixed standard is supposed to do. No-one is sure why. One theory is the gradual release of gas from the cylinder, which was forged in the 1880s.

So now the idea is to define the kilogram in terms of truly fundamental constants whose value was fixed at the birth of the Universe, and remain constant throughout space and time. Measure the speed of light in a vacuum, for example, and it's always the same.

That's the aim of the watt balance: an incredibly sensitive weighing machine that will fix the amount of mass we call the kilogram in terms of fundamental constants that govern the Universe. The idea behind the watt balance is simple enough. Put the kilogram mass in one pan of a pair of scales, and then measure the force needed in the other pan to restore balance. By using high-precision electromagnetic coils to apply the balancing force, the kilogram can then be defined in terms of a force whose value is fixed for all time.

But the devil is in the details. For a start, weight is not the same as mass: it's the product of mass and the local strength of gravity. So precise measurements of the strength of gravity have to be carried out to calculate the mass. Worse still, the electromagnetic force varies in complex ways inside the watt

balance, and has to be measured using delicate quantum effects. But an ingenious set of measurements that cancels out these problems has been devised. From a formula, it spits out the mass of the kilogram, linking it to the fundamental constant governing the quantum effects used to measure it, known as the Planck constant.

Watt balances like the one at the National Research Council (NRC) in Canada are expected to pin down the kilogram with mind-boggling precision – to the nearest 0.00000002kg. In contrast, your weighing scales are probably only accurate to the nearest 0.1kg. "Using the Planck constant will give us a clear realisation of mass without depending on a lump of metal that is constantly changing weight," says Dr Dave Inglis, watt balance project leader at the NRC. ➔

STRANGE BUT TRUE

The watt balance is so sensitive to magnetic fields it can sense when trains leave a station a few kilometres away and is even susceptible to the wind blowing trees and lifting the ground slightly. These effects have to be compensated for during the experiment.

The National Physical Laboratory is studying the speed of molecules of argon gas in this copper sphere, to help pin down the Boltzmann constant

STRANGE BUT TRUE

The triple point of water – the basis for temperature readings – is measured using a blend of distilled ocean water. This is because different forms, or isotopes, of oxygen and hydrogen are present in varying amounts in the world's oceans. Having an official water mix ensures that 0°C is the same all over the planet.

THE ULTIMATE THERMOMETER

How the speed of jiggling atoms will define temperatures in the future

TO THE NAKED eye it looks perfect in shape – a sphere of copper so smooth that any irregularities on its surface can only be seen under a microscope. It is just one part of a delicate experiment that is likely to lead to an overhaul in how temperature is measured, allowing readings to be accurate even at extremely high and extremely low temperatures.

Since 1954, temperature has been defined rather inelegantly in terms of the triple-point of water – a mixture of pressure and temperature where H_2O exists as a liquid, gas and solid. This triple point is actually 273.16K on the Kelvin scale or 0.01°C. The lowest possible temperature is

OK, or absolute zero. So Kelvin is a simple scale based on these two points. But at extremes in temperature – millions of kelvin, and close to absolute zero – this system breaks down because it is, after all, just a crude scale. That's a problem if you want to measure, say, the temperature of a nuclear explosion.

So the hot topic in temperature research is determining something called the Boltzmann constant. This relates the amount that atoms or molecules jiggle around in a liquid or gas – the amount of kinetic energy they contain, in other words – with temperature. Knowing the Boltzmann constant would mean that by measuring atoms jiggling in something, you would be measuring its temperature

directly and accurately. We currently have estimates of the constant, but physicists need to come up with a highly accurate figure they can rely on for it to form the central part of temperature measurement.

At the National Physical Laboratory in Middlesex they've been trying to do just that by measuring the molecular speed of argon gas at a given temperature. They're doing this by firing sound waves into a copper sphere containing the gas and performing calculations that reveal the molecular speed from the frequency of the sound that emerges. The perfection of the sphere is vital for these calculations, allowing the exact volume of gas to be measured.

THE ULTIMATE **RULER**

A mind-bending phenomenon will allow measurements accurate to a trillionth of a metre

IF YOU WANT to produce precise blades for jet engines or highly accurate medical equipment, you would use laser interferometry – a technique that enables eye-wateringly accurate distance measurements. But a new method is likely to become ruler of the world: atom interferometry.

In laser interferometry, a beam of light is split into two halves. One beam reflects off a mirror into a detector, while the other shines through the object that needs to be measured before it reflects off a second mirror and into the detector. Because the path one beam travels is fixed while the other beam travels an extra distance – through the object – the two light beams interfere when they meet in the detector. It's the pattern of this interference that reveals the size of the object.

Atom interferometry uses the same principle – two beams travel different paths before meeting in a detector, their interference revealing the size of an object. But here it's the same atoms that make up the two beams that are detected, something made possible by quantum phenomena – the strange behaviour of matter at the level of subatomic particles.

Atoms can be made to act like waves if cooled to near absolute zero – something that can be achieved by firing a laser at them. Firing other lasers at these atoms also puts them in a superposition of states where they are in two different places at the same time, flying along different trajectories. If the route an atom takes along one of the paths varies from the other by as little as one picometre – or one trillionth of a metre – thanks to an object being in the way, this can be detected.

Physicists at NASA's Goddard Space Flight Center and Stanford University in the US are currently developing an atom interferometer in which lasers are fired at rubidium atoms to create measuring beams. The team believes that it will be capable of detecting gravitational waves produced when massive objects, such as stars, disrupt the fabric of space-time – making objects move by miniscule amounts.

The NASA/Stanford team envisions three spacecraft flying in a triangle formation, each equipped with an atom interferometer. If a gravitational wave rolled past, the interferometers would measure the miniscule movement of one craft in relation to another. ■

STRANGE BUT TRUE

The Laser

Interferometer Gravitational Wave Observatory in the US is currently the world's most accurate ruler. It is so sensitive it can detect a change in length the size of your thumb on something on the scale of the entire Milky Way.



DR MICHAEL BANKS is the news editor of *Physics World*

Find out more



Coming soon to BBC Four: *The Measure Of All Things*, presented by Professor Marcus du Sautoy

HOW DINOS CONQUERED THE W

PHOTO: THINKSTOCK

Dinosaurs beat the competition, but it almost didn't happen...

AU RS ORLD

The dinosaurs' rise to dominance was once thought to be driven by brute force. But, says **Dr Darren Naish**, that's far from the truth

THE MESOZOIC ERA – the vast span of time that extended from 250 to 65 million years ago – is famously described as the ‘Age Of Dinosaurs’. It was once thought that these mighty reptiles were able to rule the planet due to sheer brute force alone, but a discovery made 50 years ago of the earliest large dinosaur known, called *Herrerasaurus*, would turn this idea on its head. Subsequent fossil finds in recent years have added weight to the argument that the dinosaurs didn’t out-muscle rivals to become the dominant force. Indeed, it now seems that their success was nothing more than a fluke.

Discovering how the dinosaur age got started has never been an easy task. Species from the Triassic period at the dawn of the Mesozoic have been known since the 1800s. But the creatures discovered, including the bipedal predator *Coelophysis* and the omnivorous, long-necked *Plateosaurus*, are mostly from the latest part of the Late Triassic – they are about 210 million years old. These animals are fairly large, 3m long or more, with sophisticated skulls that show that they are relatively advanced members of the dinosaur family tree. The lack of older, more primitive, dinosaurs long made it difficult to understand what happened during the earliest stages of their evolution.

It was the discovery of *Herrerasaurus* in 1963 that gave us a window into some of the earliest years of the dinosaurs. A team led by Argentine palaeontologist Dr Osvaldo Reig studied the remains of a surprisingly old dinosaur at Ischigualasto in northwestern Argentina. Reig named the animal *Herrerasaurus* after local

farmer Victorino Herrera, who first spotted the fossils. These remains are from the earliest part of the Late Triassic, and hence are about 230 million years old. Reig knew *Herrerasaurus* was a predator of some sort, but the remains were not good enough for him to reconstruct the animal’s appearance and lifestyle confidently.

Far better specimens were discovered in 1988, when Dr Paul Sereno at the University of Chicago and colleagues searched anew at the same spot. Thanks to these finds, we now know *Herrerasaurus* was bipedal, with a narrow snout, long, ‘re-curved’ teeth that curve back making it hard for prey to escape, and large raking claws on the inner three fingers of its five-fingered hands. It was large, reaching 4.5m – roughly the length of a large car – and weighing perhaps 200kg. To date, *Herrerasaurus* remains the oldest large dinosaur we know of. Compared to dinosaurs from the Jurassic and Cretaceous, the two later periods within the Mesozoic, 4.5m is not large at all. But compared to other dinosaurs from the early part of the Late Triassic, it was a giant.

In 1991, Sereno and colleagues discovered another Ischigualasto dinosaur,

“It’s become clear that the earliest, timid, dinosaurs did not go through a rapid evolution”

later dubbed *Eoraptor*. It seems to have been a far more typical Triassic dinosaur, and indeed a variety of similar-aged species are now known. All are lightly built and less than 2m long. Most must have been omnivores, foraging in the undergrowth and mostly keeping out of sight. The timid species discovered belong to different branches of the dinosaur family tree, so we can be sure that being small and inconspicuous was the lifestyle adopted by most early dinosaurs.

THREE’S A CROWD

These early dinosaurs were far from alone in the Triassic world. Dinosaurs are part of a major group of reptiles termed archosaurs. Early in the Triassic, archosaurs diverged into one lineage that led to dinosaurs and later to birds, and another that led to crocodiles and their kin. These are respectively termed ‘bird-line’ and ‘croc-line’ archosaurs.

Some of the croc-line archosaurs that lived in the Triassic were top predators. At more than 5m long, they were able to attack and defeat an animal like *Herrerasaurus*. In fact, many croc-line archosaurs evolved body shapes and lifestyles that mimicked those of the dinosaurs that would emerge more than 50 million years later.

Meanwhile, the ancestors of mammals – the synapsids – included small, furry, mammal-like forms as well as tusked, pig-sized herbivores and badger- and rat-sized omnivores and predators. For much of the 20th Century, it was believed that dinosaurs were competitively superior to croc-line archosaurs and synapsids. It was thought that members of these groups literally tussled for dominance on the Triassic plains and with their long, erect legs, clawed hands and sprightly abilities, the dinosaurs were able to win the evolutionary arms race. Croc-line archosaurs would, so it was supposed, have had to abandon their claim on the land and eke out a living forever afterwards as marsh- and lake-dwelling crocodiles and alligators.

But new discoveries have painted a more complex picture. Claims that dinosaurs were special relative to other archosaurs and to synapsids no longer ring true. The earliest, timid dinosaurs did not go through a rapid evolution that would turn them into fighting machines.

Since 2003, there has been a burst of discoveries of dinosauriform fossils – dinosauriforms being the creatures that gave rise to the dinosaurs and lived alongside them for millions of years in the Triassic. These new fossils



Palaeontologist Dr Paul Sereno holds a skull of *Herrerasaurus* found in Patagonia

PHOTO: CORBIS, NOBUMICHI TAMURA X2, GETTY, SMOKEYBJB/WIKI

THE DINOSAUR VS...

Traditionally considered the dominant force in the Mesozoic, dinosaurs weren't the biggest, or fiercest, prehistoric heavyweights



EORAPTOR (DINOSAUR)

SIZE: 1m long

DIET: Leaves, buds and small animals

ATTACK AND DEFENCE: Mostly relied on speed to escape danger

Eoraptor was a typical early dinosaur. Like the dinosauromorphs that were its close relatives, it was a small, slender, long-legged omnivore that would have been in danger of being eaten by big, predatory croc-line archosaurs. Short forelimbs show that *Eoraptor* was bipedal. It had five slender digits on each 'hand' with curved claws on the end of three of them. These claws could have been used in fighting as well as manipulating plants during foraging. Its jaws contained both leaf-shaped teeth as well as re-curved fangs.

...THE RIVALS



SILESAURUS (DINOSAUFOMORPH)

SIZE: 2.3m long

DIET: Leaves, buds, small animals

ATTACK AND DEFENCE: Weak bite - mostly relied on running from danger

Silesaurus and related dinosauromorphs were slender, long-limbed quadrupeds that would have avoided the attentions of both predatory croc-line archosaurs and early predatory dinosaurs. A small head and teeth suited for cropping leaves suggest that these animals ran away from danger. Dinosauromorphs similar to *Silesaurus* gave rise to dinosaurs some time during the Middle Triassic. Fossils, first described in December 2012, appear to be from the earliest-known dinosaur, *Nyasasaurus parringtoni*, which dates from this era.



SAUROSUCHUS (CROC-LINE ARCHOSAUR)

SIZE: 7m long

DIET: Smaller croc-line archosaurs, dinosaurs, dinosauromorphs

ATTACK AND DEFENCE: Slashing bites taken with huge fangs and powerful jaws

Saurosuchus was one of the largest and most terrifying of the rauisuchians, a group of predatory croc-line archosaurs. Quadrupedal, erect-limbed and probably fast and agile for its size, it would have been an arch-predator, capable of killing most animals of the time, including dinosaurs like *Herrerasaurus*. Its skull was deep but narrow, with long, curved, serrated teeth lining the jaws. Armour plates protected the top of its neck, back and tail.



POPOSAURUS (CROC-LINE ARCHOSAUR)

SIZE: 4m long

DIET: Smaller reptiles, including dinosauromorphs

ATTACK AND DEFENCE: Slashing bites, long fangs, ability to rear up on hind legs

Poposaurus looked like a large predatory dinosaur, but was actually a bipedal croc-line archosaur. *Poposaurus* was a long-tailed, long-legged predator with short forelimbs. It was presumably a swift bipedal runner that used a deep upper jaw and long, re-curved teeth to inflict fatal damage to prey. It is one of several croc-line archosaurs that show how members of this group independently evolved the sort of body shapes seen later in dinosaurs.



EXAERETODON (SYNAPSID)

SIZE: 1.8m long

DIET: Leaves and stems of tough plants

ATTACK AND DEFENCE: Powerful bite with fangs and broad, shearing teeth. Hides in burrows.

Exaeretodon represents the synapsids, the hot-blooded, often furry Triassic ancestors of mammals. A short-legged, tubby-bodied animal, *Exaeretodon* used its shearing cheek teeth and powerfully muscled, broad jaws to slice up tough plant material. Curved, fang-like teeth at the front of the mouth could have been used in fighting. These animals were not speedy runners and probably dug burrows for shelter and to run to in a hurry to escape the clutches of larger, predatory animals.

6 per cent of terrestrial animals were dinosaurs before the extinction events of the Late Triassic

30 million years is the length of time that early dinosaurs remained small and inconspicuous

75 teeth were present in the jaws of the Triassic predatory dinosaur *Herrerasaurus*

WHAT IF... ...the dinosaurs' competitors survived?

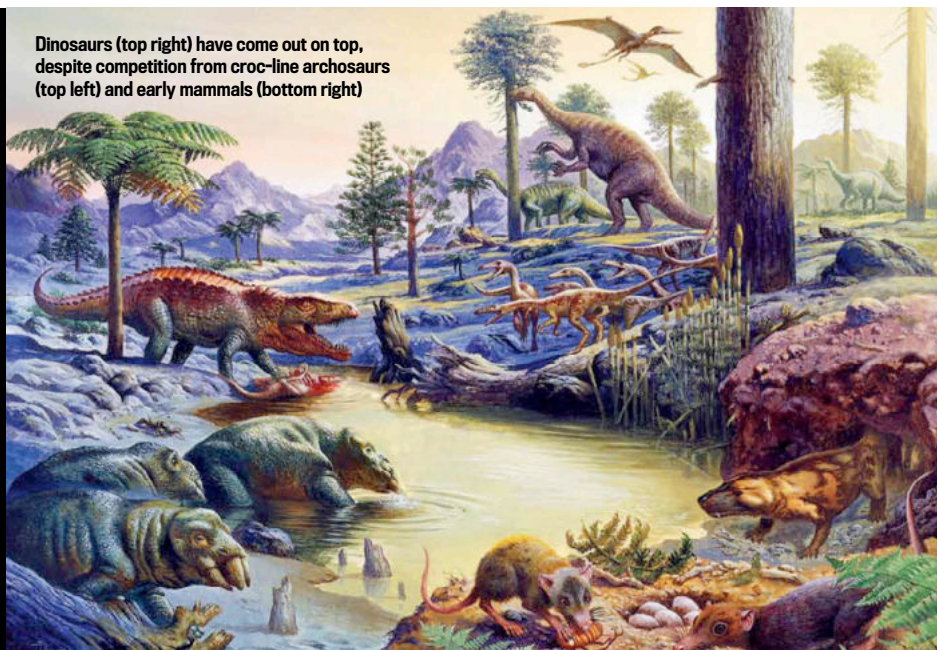
The latest evidence shows that the dinosaurs owe their rise to world domination to two extinction events at the end of the Triassic period. But what if these extinction events never occurred?

For starters, it's likely that the croc-line archosaurs would have persisted as top predators. Ironically, this means that the appearance of amphibious, freshwater crocodiles and alligators would have been prevented. The persistence of their ancestors would have left no ecological niches to fill in swamps and rivers.

Dinosaurs and other bird-line archosaurs would have continued to live in the background and would have remained small. The dominance of the croc-line archosaurs would have left few ecological niches for the dinosaurs to exploit, so many of the species we know to have existed would not have developed. Interestingly, this means that birds would not have appeared, since their origin was contingent on the diversification and success of predatory dinosaurs.

What about mammals? As in the real world, we can be confident that small

Dinosaurs (top right) have come out on top, despite competition from croc-line archosaurs (top left) and early mammals (bottom right)



burrowers, swimmers and climbers would have evolved during the Mesozoic, and would mostly have tried to avoid the attentions of croc-line archosaurs. The evolution of large mammals with unusual body shapes – whales, antelopes and humans, for example – would have depended on the asteroid that killed off the dinosaurs 65 million years ago killing off croc-line archosaurs.

However, if we imagine that this extinction event at the end of the Cretaceous did finally

knock the croc-line archosaurs out of the game, mammals would now have to contend with small-bodied dinosaurs. It's likely the dinosaurs – still small and inconspicuous – would have lived through the asteroid strike. The mammals and dinosaurs would have raced to evolve a large size, and there are no obvious indications that one would succeed above the other. Perhaps, our modern world would have been jointly ruled by big mammals and big dinosaurs.

→ have shown that dinosaurs were not especially different from the dinosauiromorphs. So the dinosaurs emerged quietly, without any dramatic increase in body size or important shift in lifestyle or ecology from among this group of small predators or omnivores. Looked at objectively, there is nothing in the fossil record that makes the success of dinosaurs look at all inevitable. In fact, it was a world that belonged to croc-line archosaurs. So, what happened? How did dinosaurs go

from being small, furtive animals of the background to a dominant global force?

The strongest evidence appears to show that two mass extinction events – both occurring during the last part of the Triassic – removed large-bodied synapsids and croc-line archosaurs from the equation, leaving dinosaurs to rule the world.

The first of these extinctions happened about 220 million years ago. Many larger-bodied synapsids died off at this time, as did various non-dinosaurian

reptile groups and numerous marine species. A climatic change, perhaps triggered by the splitting of the Pangaeian supercontinent – the huge landmass that incorporated all the continents we now see – caused aridity in many areas. It has been suggested that the resultant change in vegetation and rainfall initiated a cascade of ecological consequences.

The second mass extinction event happened at the very end of the Triassic, 200 million years ago. It seems to have

RISE OF THE DINOSAURS

The timeline of the Mesozoic era is littered with species vying for supremacy

EARLY TRIASSIC (252-247Ma)

250Ma Ma = millions of years ago

Bird-line archosaurs and croc-line archosaurs diverge from one another



MIDDLE TRIASSIC (247-235Ma)

240Ma

Emergence of the first true dinosaurs, such as *Nyasasaurus*



caused major, rapid changes to the global flora and fauna. The impact of an asteroid is a likely cause of this event, just as it is for the extinction event of 65 million years ago that wiped out the dinosaurs themselves (except for the birds, the lineage of dinosaurs that survived).

There is even a potential 'smoking gun' for this Triassic strike: the enormous Manicouagan Crater in Quebec. Representing the impact site of an object perhaps 5km (3 miles) across, it is presumably big enough to have caused major perturbations in the global ecosystem. Similar-aged craters in western Canada, France, the Ukraine and North Dakota have been suggested as evidence for a series of impact events.

The Manicouagan Crater means it might have been formed as much as 214 million years ago. But several pieces of evidence in recent years, including a burst in fern growth, have provided support for another impact happening at 200 million years ago. It's known that when other plant species are wiped out, ferns enjoy a huge growth in population. Less controversial is the massive volcanism that occurred at the same time in the northern part of Pangaea. It appears to have caused global warming and ecosystem collapse.

RULING THE ROOST

After these events, dinosaurs flourished – the fact that they made 50 per cent of the tracks we now see from this time is evidence for this. Furthermore, the size of the track-makers doubles during the same period. As big animals that were living out in the open and sitting at the top of their respective food pyramids, croc-line archosaurs were presumably more adversely affected by the extinction events than the mostly small, ecologically generalised dinosaurs. The general pattern of the fossil record shows croc-line archosaurs doing okay prior to the event, but are all but absent after it.



The Manicouagan Crater in Quebec is thought to have been caused by a 5km-wide asteroid at the end of the Late Triassic

“How did dinosaurs go from being small, furtive animals of the background to a dominant force?”

The dominance of dinosaurs, then, appears to owe itself to the fact that many of their competitors simply disappeared. Had those extinctions not occurred, the Mesozoic could have been the age of the crocodile rather than the dinosaur. Fifty years on from the discovery of *Herrerasaurus*, we know that the dinosaurs weren't as formidable a force early on as was once thought – they were fortunate survivors. ■

Dr Darren Naish is a palaeontologist at the University of Portsmouth and the author of *Great Dinosaur Discoveries*

Find out more



Watch *Walking With Dinosaurs* videos on Earth Unplugged, a new YouTube channel at www.youtube.com/user/EarthUnpluggedTV

MESOZOIC ERA (250-65Ma)

LATE TRIASSIC (235-201Ma)

JURASSIC (201-145Ma)

230Ma

220Ma

210Ma

200Ma

Eoraptor and *Herrerasaurus* are now roaming Earth

EXTINCTION EVENT

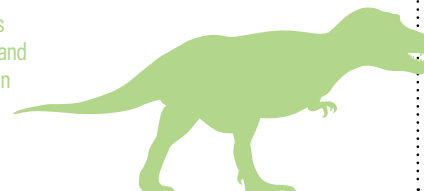
Synapsids decline after mass extinction event

Croc-line archosaurs at an all-time high in terms of diversity

Earliest mammals appear, such as *Megazostrodon*

EXTINCTION EVENT

Dinosaurs diversify and increase in body size



DOES NOT COMPUTE!

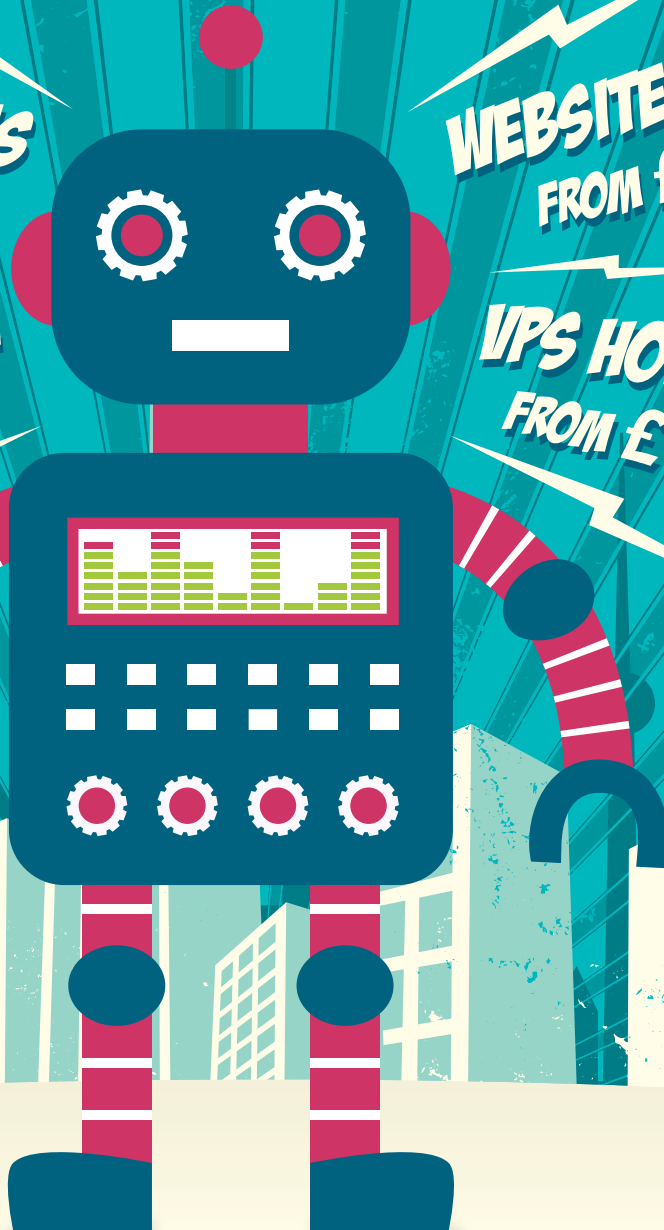
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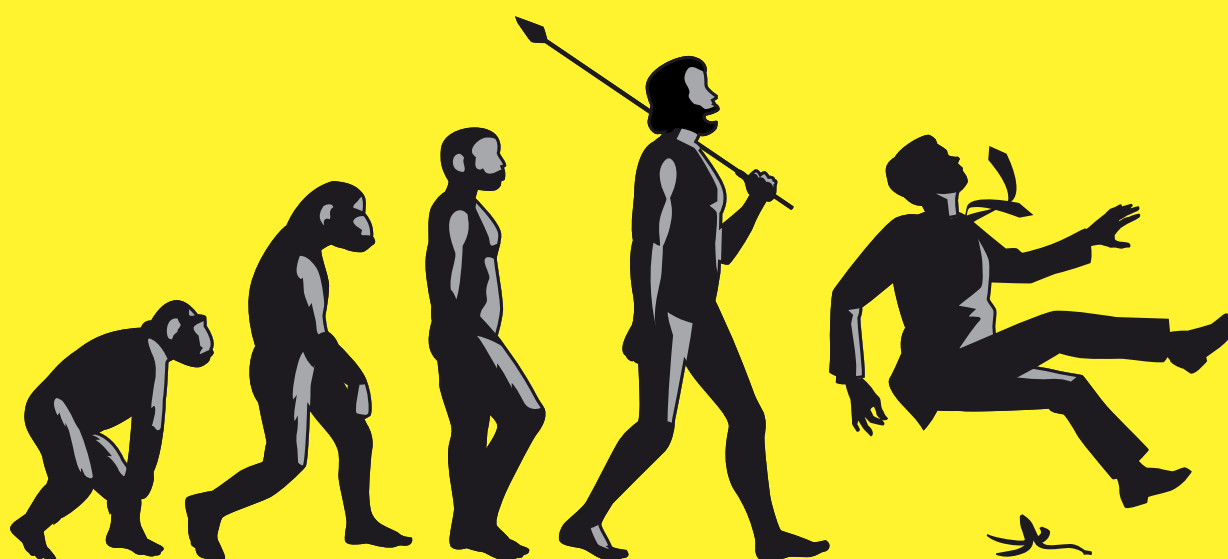
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NOBODY'S PERFECT

Are humans hardwired to make mistakes?
Neuroscientist **Dean Burnett** explains
what makes people prone to error

SCIENTISTS ARE A notoriously devious bunch, psychologists particularly so. To prove just how susceptible people are to making mistakes in the real world, and not just in controlled experiments, a group of researchers at Cornell University took one of their tests out onto the streets.

They would send an experimenter holding a map to ask an unsuspecting passer-by for directions. Halfway through the conversation, some workers carrying a large piece of wood would walk in between the two, temporarily obscuring the secret scientist from view. At this point, the researcher would swap

places with a colleague who was hiding behind the large block of wood. The member of public was now talking to a completely different person, so you'd think they'd be a little shocked, but in more than half the cases, they weren't. They hadn't even noticed the difference.

As BBC presenter Dr Kevin Fong reveals on *Horizon* this month, mistakes can be costly when they're made by doctors. But how does human error happen? Research like that being carried by the devious psychologists is starting to shine a light on our fallibility. Indeed, the aforementioned example is known as change blindness. ➔

ILLUSTRATION: WILLIE RYAN

→ It's the by-product of the brain's limited processing capacity. Since the brain doesn't expect some tricky scientists to be trying to fool it, it doesn't waste vital processing power constantly checking every detail. The end result is an embarrassing, if slightly unfair, mistake.

In fact, we all make simple mistakes every day. But don't feel bad: the human brain is littered with pitfalls and trapdoors. In fact, bugs, glitches and errors are practically coded into our brain's 'software'.

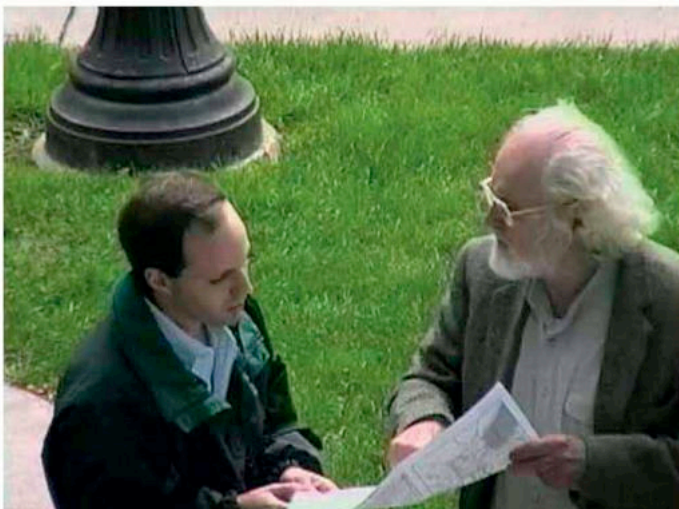
Most people will have experienced that familiar 'jerk' when trying to sleep, usually accompanied by a falling sensation. This is known as a hypnagogic myoclonic jerk, and is thought to occur because the brain misinterprets the signals resulting from falling asleep as signals of literal falling. It reacts by tightening up your muscles to reassert balance, causing a sudden, violent



Motion sickness is caused by information sent to the brain by the eyes contradicting information sent by other organs

jolt. Why the brain makes such a mistake is unclear, but it demonstrates how the brain gets confused at a subconscious level by things that would seem embarrassingly simple to our conscious minds.

Another such example is motion sickness, which occurs when there is a conflict between what the visual system and vestibular (balance and movement) system are telling the brain. One is saying, "Everything's fine, no motion here," while the other is saying the exact opposite. This ends up confusing the unconscious brain. The most likely thing in nature that could feasibly create such a disturbing mismatch between the two systems is a harmful neurotoxin. Panicked, the unconscious brain tries to purge this potential poison by vomiting, which is essentially the brain's equivalent of rebooting – much to the dismay of your fellow passengers.



In the Cornell University study, a researcher would ask a passerby for directions (a). As two workmen walked past carrying a piece of wood (b), the researcher would swap places with a colleague hiding behind it. In many cases, the unwitting test subject failed to notice (c) that they had actually been speaking to two completely different people (d).

“The visual system does a lot of work for our brains, and demands preferential treatment in return”

The dominance of the visual system over the human sensorium can lead to many mistakes by the brain, several of which we are fully aware of. For example, the ability to watch motion pictures is technically a fundamental error. Still images are presented to us so rapidly that our visual systems fail to keep up and they're perceived as movement, when nothing is 'moving' in the strictest sense. And our eyes often override our ears, even when the latter is providing the accurate information. Cinema sound systems have speakers on the periphery of the room, but we perceive the sound to be coming from the screen. This isn't happening, but our eyes convince our brain it is.

If the visual system is so fallible, why does the brain pay it so much heed? Some estimate as much as 65 per cent of brain regions are connected to the visual system in some way. In humans, the fovea measures only 1mm². This is the part of the retina that has enough photoreceptors to perceive the detailed images we need for reading and other complex visual tasks. If the fovea doubled in size, your brain would have to become at least as big as a basketball to process the information. So the visual system does a lot of work for the brain, despite not being 100 per cent reliable.

Our unconscious brains seem to be configured with mistakes built-in. But once we get to the conscious level, surely humans are less likely to make errors? You'd think so – but you'd be wrong.

GREED TRUMPS LOGIC

Humans base most of their decisions on heuristics, or rules of thumb, which while efficient are unlikely to be accurate all the time. In a series of Nobel Prize-winning experiments, Daniel Kahneman and Amos Tversky showed that people based their decisions on the potential value of losses and gains rather than the final outcome. For example, a person may refuse to bet a further £5 in a card game



HOW THE PROS AVOID MISTAKES

In the new series of *Horizon*, Dr Kevin Fong of University College London Hospital explains how medicine can prevent fatal errors by learning from other professions



Dynamic Risk Assessment helps keep firemen alive



US Airways Flight 1549 ditched safely on the Hudson River in 2009



F1 pit crews have procedures in place for every eventuality

FIRE-FIGHTERS

Our brain has a finite capacity to cope with fast-moving, complex situations. It's only human to make bad decisions in high-pressure scenarios. In our evolutionary history the most fast-moving situation would have been 'Uh-oh, there's a sabre-toothed tiger, do I run or do I fight?' To counter this, the Fire Brigade teaches something called Dynamic Risk Assessment. When you have a time-dependent, complex task that you have to perform correctly, it's easy to focus on one element and miss the bigger picture. It's called cognitive tunnelling. In the case of a fire-fighter, it might be that an oil tanker could explode while they're putting out a fire in a nearby building. The idea is, at regular intervals, a person should step back from their task to look at the problem as a whole before returning to that specific task.

AIRLINE PILOTS

I met Chesley Sullenberger, the pilot that landed Flight 1549 in the Hudson. That situation was similar qualitatively to the kind of emergencies we face in surgery. Having had both his engines taken out on the climb out of La Guardia, his response was to turn to his co-pilot and start reading the checklist off. The airline industry actually has a system of checklists not only to prepare you for an emergency, but that you follow while a catastrophe unfolds. It standardises your response so you're not having to improvise. In reality, there's no Bruce Willis moment where a miracle solution occurs to you. Sticking with the plan until it's no longer applicable eliminates the chance of human error. If a checklist helped Sullenberger in that situation then perhaps doctors, and the general public, can do something similar.

F1 PIT CREWS

We're used to thinking of the effort of surgery as being in the actual theatre. But the patient's still on life support and there are still critical decisions to be made. You're breathing for them, you're supporting their heart with drugs. You arrive after five- or six-hour operations and say, 'This patient had this operation, here they are', and inevitably, mistakes creep in. But if you look at F1 pit crews, who rarely make mistakes, they stereotype each behaviour and role, so that each action and role is completely automatic. This same approach has recently been applied to transferring patients post-surgery at Great Ormond Street hospital, with success. Automating parts of any process where you can take decision-making out of human hands reduces the chance for error.

THE HUMAN BODY: A CATALOGUE OF ERRORS

It's not just your brain that blunders, your body is full of flaws too. Here's why you're far from physically perfect...

EARS

Around 70 per cent of children get an ear infection before they're three. The canals that connect our ears to our brains are too long and narrow for air to circulate inside, which makes them the ideal home for bacteria to flourish in. The hairs in our ears that allow us to hear are also damaged by sound over time, which is why we lose our hearing with old age. Birds, by comparison, simply grow new hair cells to replace old ones.

SPINE

Our upright stance puts excessive pressure on the spine, resulting in the regular occurrence of back pain. The spine initially evolved for a quadruped skeletal structure, where pressure on it was more balanced. Bipedal physiology isn't so friendly, hence the backache.

APPENDIX

This little-used organ appears to be somewhat redundant these days. It's a body part that had a function, but one that is not required thanks to evolution, although the physical part remains. Some studies indicate it could help prepare us for future infections, but for the most part the appendix occasionally gets infected, explodes and kills you for no real reason.

EYES

Our retinas are back to front, as the nerves and blood vessels that support them are in front of the photoreceptors, meaning images have to pass through them to be seen, like a net curtain obscuring the view. Blood vessels then have to pass through the retina, creating blind spots.

TEETH

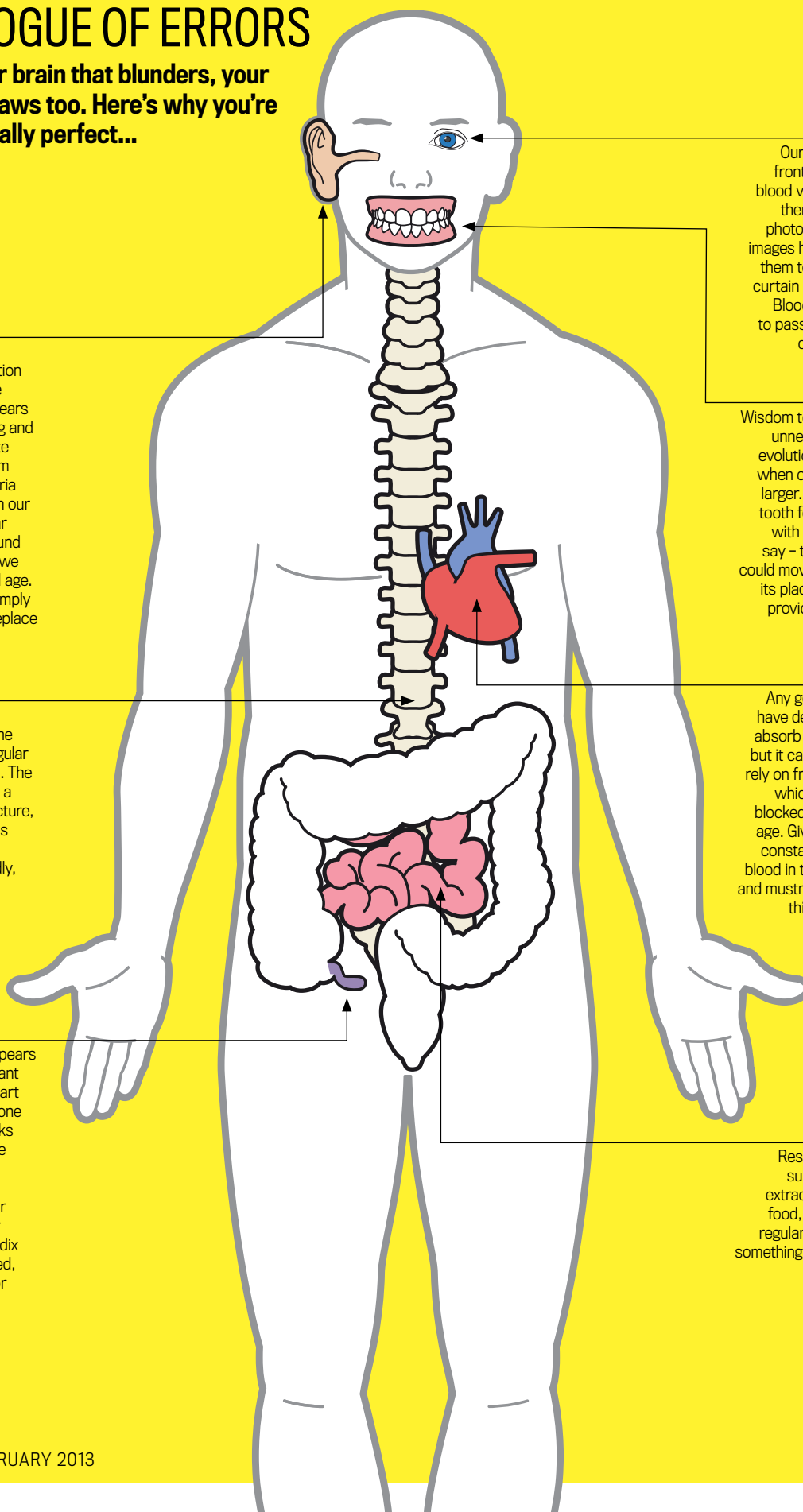
Wisdom teeth are completely unnecessary. They're an evolutionary throwback to when our jaws were much larger. It's thought that if a tooth fell out – after a fight with a woolly mammoth, say – that a wisdom tooth could move forward and take its place. Now they simply provide excruciating pain to millions.

HEART

Any good engineer would have designed the heart to absorb oxygen from blood, but it can't. Instead it has to rely on fragile blood vessels, which regularly become blocked or damaged as we age. Given that the heart is constantly pumping *all* the blood in the body *all* the time and mustn't stop at any point, this seems inefficient.

INTESTINES

Responsible for the life sustaining process of extracting nutrients from food, your intestines are regularly incapacitated by something as basic as gluten.



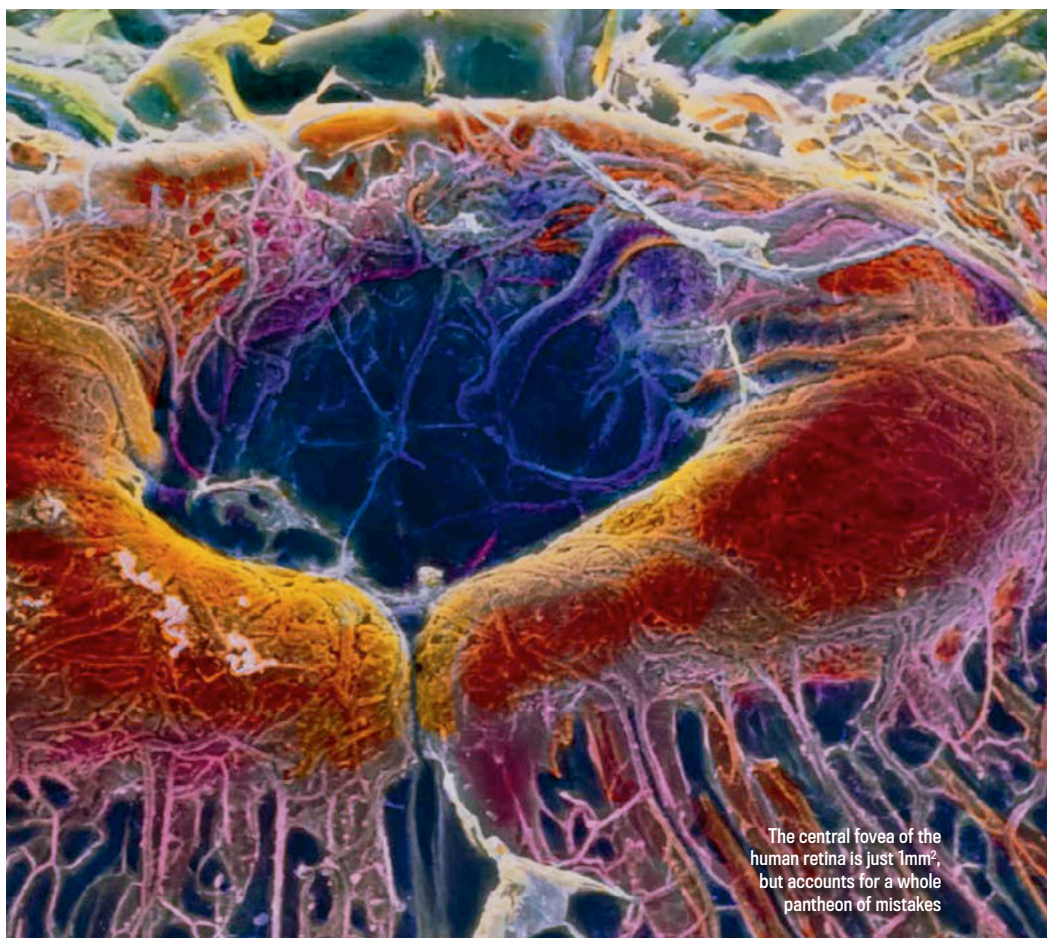
“Even our own memories can’t be trusted: they are quite malleable and vulnerable to suggestion”

→ in which they’ve lost repeatedly, despite the fact that the odds of them winning are the same as every previous bet. The same person may then spend £5 on lottery tickets, where the prize is much greater, but astronomically unlikely in comparison to the card game. This tendency to behave inconsistently and in defiance of likely outcomes, in the pursuit of large gains, lies behind the majority of mistakes we make when forming decisions.

Even our own memories can’t be trusted. Rather than a straightforward record, our memories have been shown to be quite malleable, and vulnerable to suggestion or leading questions. Researchers like UCL psychologist Elizabeth Loftus have shown in experiments that, with a combination of simulated video, leading questions and false information, people can remember details of events and incidents they were never involved with, but that they have apparent memories of. They’re not lying; they genuinely believe their memories are accurate. But they’re mistaken. And even outside of the lab and active manipulations like this, people have a strong tendency to emphasise their own role in events beyond all accuracy when recalling them.

This sort of thing was first picked up on in the Watergate trials, when there were physical recordings of events that witness testimonies could be compared to. Those involved who were willing to testify often emphasised their own involvement in ways that were usually contradicted by the recordings. It seems our weak memories are trumped by our strong egos.

On a similar subject, a 2006 study at the University of Virginia reported that jurors found witnesses who were more certain in their claims than others (eg, those that said “That happened” as opposed to “I think that happened”) the most credible type of witnesses – unless other evidence suggested their testimony was incorrect. So it’s possible that, even in very important contexts, we’re swayed by confidence and presentation more than we should be.



The central fovea of the human retina is just 1mm², but accounts for a whole pantheon of mistakes

Which is probably why your typical politician is confident and slick in what they say, but rarely says straightforward things that can be shown to be wrong without detailed analysis. This may explain why we repeatedly vote for these people: they’re exploiting a quirk of human nature.

COPING MECHANISMS

If we humans are such a ridiculous assemblage of constant mistakes and flaws, how do we survive at all? Well, we have a number of systems to compensate. At the conscious or subconscious levels, when we make a mistake that has serious consequences, our brains don’t let us forget it easily. The amygdala makes sure we remember the unpleasant emotional experiences (fear, embarrassment, shame) that result from mistakes that lead us into danger or social calamity.

Then there’s the insula and putamen, brain regions that make up part of the telencephalon, which is responsible for some fundamental cognitive processes. These make doubly sure we avoid anything that has made us sick by ensuring we experience revulsion at the mere thought of it from then on.

And a University of Michigan study may have identified a supposed ‘oops’ centre of the brain using brain imaging techniques. Researchers found that a region in the brain’s frontal lobe called the rostral anterior cingulate cortex, which is associated with emotions, was activated far more when participants incurred a penalty on a test, than when they just missed a reward. This suggests it is activated whenever our mistakes have tangible consequences, presumably to ensure those mistakes don’t happen again.

It’s a cliché maybe, but mistakes are important for us to learn and grow. They make us what we are. As Alexander Pope once said: “To err is human”. ■

Dean Burnett is a doctor of neuroscience at Cardiff University, a stand-up comedian and author of the *Guardian* blog *Brain Flapping*

Find out more



Kevin Fong’s *Horizon* documentary on how mistakes can be avoided in medicine airs on BBC Two in February

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Small enough to pick up with one hand yet big enough for a lifetime of music, the Brennan JB7 is a CD player with a hard drive that lets you store, browse and play up to 5000 of your CDs. It also records from vinyl and tape and loads music direct from your iPod or MP3 player.

Just think, no more clutter, no more hassle, just every album you've collected over the years, every favourite track - instantly available at the touch of a button. JB7 owners rediscover then fall in love with their music again simply because the Brennan makes it so accessible.

The Brennan JB7 also comes with a full money back guarantee, so if it's not for you it will cost you nothing and in the meantime you'll have a great weekend encountering your music all over again.

"Quite honestly, it's the best thing I've bought in years!" Mr B, Dorset

THE BRENNAN JB7 LETS YOU STORE, BROWSE AND PLAY UP TO **5000 OF YOUR CDs***



Built-in hard drive - loading each CD takes JUST 3 - 4 MINUTES!



Album and track names are automatically added!



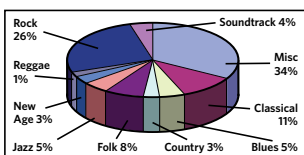
Combines tracks in ways you would never dream of!



Find the music you want to hear in SECONDS!



NEW FOR 2012 Load or play music from your iPod†



Massive CD database on the Brennan JB7's hard drive contains the titles of 3.0 million albums including their track names.

OVER 40,000 ALREADY SOLD

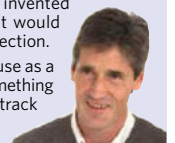


- Big bright display lets you search and play from across the room
- One button plays your music
- Room filling sound
- Segue function - blends one track to the next without interruption
- Just two clicks to load a CD - load 30-40 in an evening
- Find specific tracks or albums in seconds without leaving your chair
- Plays your online/iPod music collection
- Rainbow colour coded Playlists - create a mood in two clicks

The face behind the Brennan JB7

Martin Brennan has worked with Sir Clive Sinclair and Lord Alan Sugar and has designed over 20 silicon chips in his career. Ever since CDs were invented Martin longed for a CD player that would hold his entire disorganised CD collection.

He wanted something as simple to use as a light switch but at the same time something that would let him find a particular track without leaving his armchair.



VOTED 'BEST BUY' BY WHAT HI-FI. RECOMMENDED BY GRAMOPHONE MAGAZINE AND SUNDAY TIMES.



Available in all branches of Richer Sounds or direct from www.brennan.co.uk

†The 2012 JB7 links to selected iPods and MP3 players only. Check website for compatibility.

*A word about copyright In 2006 the record companies said unequivocally that they are happy for you to load your own CDs onto a hard disk but the Advertising Standards Authority have asked us to tell you that it is unlawful to copy material without the permission of the copyright holder.

THE FUTURE OF GADGETS

TECH HUB

EDITED BY **DANIEL BENNETT**

THIS MONTH

BILL THOMPSON
Wearable tech is here!
p69

JUST LANDED
Google Now
p70

ULTIMATE TEST
The Lytro camera
p75

Your doctor may soon be able to diagnose you from hundreds of kilometres away with the help of an RP-VITA telepresence robot



ON THE HORIZON

RP-VITA TELEPRESENCE ROBOT

ON A REMOTE island in the Outer Hebrides, a child is taken ill. The boy is rushed to the nearest hospital, where he's diagnosed as having an extremely rare blood disease – one that's almost always fatal. Luckily, the world's leading expert in such conditions is at his bedside in minutes and, thanks to her expert guidance, the hospital staff manage to save the boy's life. We all love a happy ending, don't we?

The above may sound far-fetched, but new technology developed by iRobot (maker

of the Roomba robot vacuum) and InTouch Health, a leader in the field of telemedicine, should ensure that such stories become reality. RP-VITA (Remote Presence Virtual and Independent Telemedicine Assistant) is a 'telepresence' robot that enables doctors to interact directly with patients who may be thousands of kilometres away.

At its most basic level, RP-VITA can be thought of as a Skype screen on wheels. Using an iPad app to control its cameras and its navigation around the room, a doctor located remotely can examine a patient, check their vital signs, ask questions and even oversee surgical procedures. In our example, the patient survives because the need to wait many hours for a specialist to arrive on-site is removed.

Similar medical telepresence robots already exist; what's different about RP-VITA is



A doctor can operate the RP-VITA via an iPad



Yes, your doctor may look like a giant chess piece, but hey, this saves lives



that it's able to navigate autonomously. So where current models need to be steered around the hospital like a remote-control car, RP-VITA can simply be instructed to go to ward 11, bed 42. Its cameras, GPS transceiver and motion sensors enable it to find its own way there, leaving the doctor to concentrate on the treatment. The robot is awaiting final approval for clinical use by the US FDA (Food and Drug Administration) and should start appearing in hospitals next year.

"There's been a lot of work done, both in industry and in academia, on autonomous robots," says Chris Jones, Director for Research Advancement at iRobot. "The challenge is getting that technology to work reliably in a non-predictable environment, and to build it in such a way that it can be operated by someone with no knowledge of robotics."

At the moment, RP-VITA still requires some human assistance. If a doctor wants to hear a patient's heartbeat, for example, a nurse needs to hold a stethoscope to their chest. "So our next big challenge," says Jones, "is for the robot to be able to apply sensors on its own. That requires an arm of some kind. That's still some way off, but we're working on it."

Dr Andrew Davison, professor of robot vision at Imperial College London, is suitably impressed by the RP-VITA. "The most exciting development here is the autonomous navigation," he tells us. "The big challenges in robotics are to make a robot that can firstly negotiate, and secondly make sense of its environment. Hospitals tend to have flat floors and wide, straight corridors, which makes the first part easier, but it's only recent advances in areas such as computer vision that make something like RP-VITA possible."

Some patients might wonder about the bedside manner of a telepresence robo-doc, but its creator Jones believes any resulting anxiety will be short-lived. "When you look at Roomba, it's incredibly popular with the elderly – the very demographic you'd think might be resistant to having a robot in their home. Once people see RP-VITA's capabilities, any concerns rapidly disappear. We've spent a lot of time getting it to work well enough that you forget you're interacting with a piece of technology."

RUSSELL DEEKS is a technology journalist and regular contributor to *Focus*

TECHOMETER

5G

WHAT'S HOT

5G BROADBAND

A successor to the 4G mobile network, 5G, is already in the works. The university of Surrey has just secured £35 million in funding to develop the next generation of mobile broadband. The university will set up an innovation centre dedicated to future mobile technologies using this money, which will trial 5G in the Guildford area in 2013. Their target is to achieve transfer speeds of up to 10Gbps, 10 times faster than what the 4G network can manage.

WHAT'S NOT

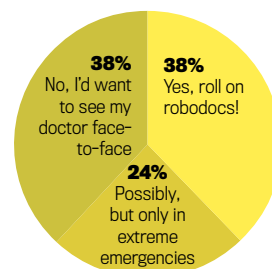
WINDOWS 8

Microsoft's latest version of Windows has disappointed critics and consumers alike. Its 'Live Tile' interface has been popular on touchscreen phones and tablets, but has left many PC users frustrated, judging by the blogosphere. But further developments could be around the corner. Rumours suggest a rolling programme of updates, called Windows Blue, might begin this summer, although it's unclear what would actually change.



READER POLL

Would you receive treatment via the RP-VITA? Here's what you've said so far.
Vote at j.mp/rpvitapoll





EARLY ADOPTER BILL THOMPSON

Wearable tech is coming out of the closet

Last year Google garnered a lot of attention with Project Glass, a pair of spectacles with a high-definition video camera, a heads-up display and a fast wireless connection, but it isn't the only company wanting us to wear the internet in some form or other. Indeed, 2013 could be the year that wearable technology evolves beyond the Bluetooth headset.

Take the games studio Valve, which runs the very popular Steam games distribution network. It has announced plans to develop an augmented reality headset for players. Or if you want to photograph your life there's Memoto, a brooch-sized device that takes a still photograph every 30 seconds to provide a permanent record of your day, uploading it constantly to the web to the irritation or potential embarrassment of those around you. The device is small enough that the potential stars of your video and photos are unlikely to know they're being filmed.

Wearable tech isn't a new idea though. Back in 2003 the Massachusetts Institute of Technology developed a system called MIThril, named after the dwarven metal armour used in *Lord Of*

The Rings, but anyone wearing it would have been as obvious as an Orc in a china shop. It loaded its wearer with an array of sensors, batteries and circuit boards so that he or she could interact with their environment digitally. Sadly, it was too heavy, obvious and clunky to be of any real use.

So why will 2013 be the year wearable tech takes off? We've known how



to make computers tiny and powerful for a while, but the key technologies that make devices compact enough to wear are small, powerful batteries and displays, and reliable wireless connections. All of which have come far enough in the last two years that together they can be hidden in jewellery, spectacles and clothes to build workable systems.

Today's generation of wearable computers, like the Nike+ FuelBand and Memoto, are really

just sensors, but they all have some processing power. When we get them working together and give them a fast internet connection, something truly remarkable could result. It could be something that will challenge the smartphone, tablet and even laptop as our preferred way to stay connected, consume content and create our own. A wearable system that would let me type, edit and paint in the air would transform the way I live, play and work.

For now, Google's Project Glass is no more than an advanced prototype, and so far augmented reality systems have failed to convince me that they offer real value. But they will improve, and alternatives will also emerge. I remember when mobile phones first appeared and it seemed strange to see people walking down the street talking into their hands. The same might be true of people wearing their gadgets: we're going to have to get used to a world in which we wear discreet technology that keeps us online wherever we are.

Bill Thompson contributes to news.bbc.co.uk and the BBC World Service

COMING SOON

3 MONTHS

LEAP MOTION



This motion sensor is tuned to track the movement of your hands and fingers. The idea is that it would give you pinpoint control of computer software through your gestures. In demos, users spin virtual globes around with their hands, zoom in and out by pinching the air and pan around maps by swiping the screen – all while keeping grubby fingerprints off your display. leapmotion.com

✦ **Nest** A smart thermostat that could slash your bills. It adapts to your habits to heat your home economically. Nest.com

✦ **Pebble Watch** With an E-ink display, this watch uses your phone's Bluetooth connection to display your email, Twitter feed and more. Getpebble.com

6 MONTHS

XBOX 720



Numerous games developers, including Bungie the creators of *Halo*, have let slip release dates of next-generation console games that point to a release of the new machine this autumn. Rumours from inside Microsoft HQ also suggest there'll be a budget version of the Xbox aimed at people who just want streaming TV and gaming. Microsoft.com

✦ **Intel Clovertrail** Intel's new generation of processors will power next-generation tablet computers, giving them longer battery lives and faster interfaces. Intel.co.uk

✦ **Project Glass** Messages, maps and information from the web will all be overlaid on top of your view with Google's new vision for the internet. j.mp/projectglass

9 MONTHS

GOOGLE NEXUS PHONE 4 (2013)



The search giant hit the jackpot in 2012 with its current 4-inch Nexus 4 handset, selling out in just one day. So this year's upgrade is likely to set the standard for the next generation of mobile phones. google.co.uk/nexus

✦ **Apple iTV** An anonymous former Apple employee reportedly told *USA Today* that the company's head designer, Jonathan Ive, is working on a 50-inch TV. Apple.com

✦ **Samsung Galaxy S4** Flexible screen technology seems to be at the top of Samsung's agenda for its next flagship phone. According to a Samsung spokesperson, it could be "foldable, rollable and wearable". Samsung.com



TELL US WHAT YOU THINK!

Would you wear a connected computer? Visit our forum at sciencefocus.com/forum and tell us what you think.



JUST LANDED

THE FUTURE IS NOW

A personal assistant in your phone that knows what you want when you want it? Joe Svetlik tries Google Now



What is it?

Google Now is a digital assistant that knows what you're up to. Whereas with Apple's Siri you have to ask for information, Now checks your calendar, emails, search history and current location to provide you with info that might come in useful. So pencil in a meeting, and it'll tell you when to leave to beat the traffic. Not only that, it becomes more accurate the more you use it. Think of it as an artificial intelligence (AI) that's trying to help you throughout the day.

How does it work?

It's integrated into Google search, so there isn't actually a separate app called Google Now that you need to open. To use Now, you'll need a phone running the Jelly Bean version of Android; to open it, just swipe up from the bottom of the screen. You'll see a series of cards with info relevant to your situation. The cards are

sparse but easily readable, and you can just swipe them away if they're of no interest. It's simple and intuitive.

Is it really helpful?

Generally, it works very well. It estimated a 24-minute journey to a lunch meeting, and was pretty spot on. Similarly, we Googled 'QPR' (Queens Park Rangers), and then the next time we opened Now it told us they had a game the next day. One click of the card brought up past results and links to the official QPR homepage.

There are some quirks, though. The cards don't update live (like Windows Phone 8's live tiles), so for directions to a meeting, you'll have to click the relevant one to open Google Maps. It's not a huge pain, but adds a stage to the process. Handily, once the meeting was over a card told us how long it'd take to get home. But then when we got home it tried to send us back to the

meeting again, two hours after it'd finished. It's a minor gripe, but annoying nonetheless.

Now is also supposed to provide train times when you approach a station, but during our tests we were near London's Paddington, Euston and King's Cross, and didn't see any alerts. Despite numerous cinema searches, we also didn't see any screening times pop up when we were passing.

And while it covers flight times, concerts, stock prices and more, it doesn't yet cover your media like albums and books. It'd be great to see an alert when your most-played artist is appearing in a show near you, for example.

But having said this, just minutes after receiving an email invite to an event, we were provided with a map to find our way there, with estimated journey times, without having to lift a finger. This is pretty impressive.

Is it worth upgrading?

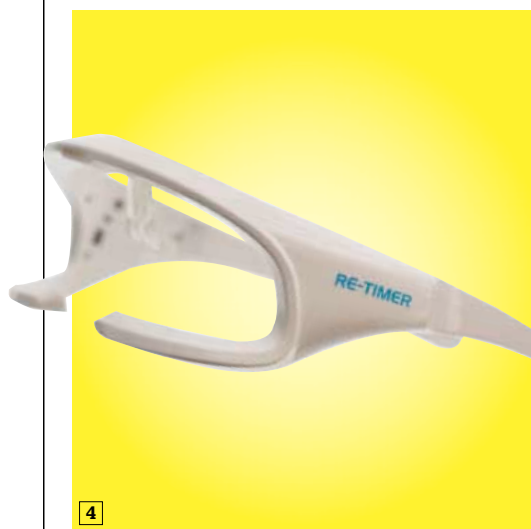
Google Now is part of Android Jelly Bean, which is only on a handful of handsets at the moment. It feels like the first step rather than a polished final product, and the novelty will soon wear off unless you're travelling a lot or constantly out doing new things. So it's probably not worth getting a whole new contract purely to use it.

That said, as it's free, we highly advise you to take Google Now for a spin if you've got a new handset with the Android Operating System. It's the kind of software that, with a few updates, could really start to make life easier. While Apple's Siri acts like a personal assistant who'll do their best to help, Google Now is more like a butler who knows what you need, even before you do.

JOE SVETLIK is a freelance tech news journalist


1

2

3

4

5

6

APPLIANCES OF SCIENCE

1 FLIPPING CLEVER

The Yoga is what happens when you cross a laptop with a tablet. During normal use, it's a standard Windows 8 Ultrabook with a touchpad mouse and keyboard. But its screen can be twisted around through 180° and folded back on to its base, transforming it into a 13-inch tablet with a handy stand. The device is light for a laptop and heavy for a tablet, but it ultimately gives you the best of both worlds.

IdeaPad Yoga
Lenovo.com, from £699

2 FILM STAR

If you're brave enough to make video calls in high definition – after all, it leaves very little to the imagination – then you may as well do it on your big-screen TV. This smart TV adaptor lets you make Skype calls from the comfort of your living room, capturing the full breadth of your surroundings with its wide-angle lens. It also adds web-browsing capabilities to your TV set and a handful of apps.

telyHD
Tely.com, £229

3 UNDER THE THUMB

Press your thumb up against this small iPhone accessory (not compatible with iPhone 5) and a sensor inside monitors changes in the volume of blood in your skin. The Tinké uses this data to make inferences about your health. It can tell you your heart rate, blood oxygen level and respiratory rate. By combining the three, it provides a very general idea of your wellbeing with a simple, trackable score out of 100.

Zensorium Tinké
zensorium.com,
\$119 (£74)

4 ALL LIT UP

Wearing these specs might make you look like an extra from *Star Trek*, but that's a small price to pay if it rids you of jet lag. Developed by two Australian sleep scientists, the Retimer is based on the idea that your body stops producing the sleep hormone melatonin when it's exposed to light. By wearing the headset at certain times in the day it slowly resets your body's inner clock.

Retimer
Re-timer.com, \$273 Aus plus P&P (£178)

5 GASTRO DOME

Who said microwaves had to be boring, big blocks that take up too much space in your kitchen? This dome-shaped device is unlike any microwave we've ever seen before. While we love it for its looks, its shape actually makes it easier to clean – there's fewer nooks and crannies. On top of this, the clear lid lets you monitor your ready-made korma from all angles, if you've got nothing better to do.

Fagor Spoutnik
fagor.co.uk, £179

6 CRYSTAL CLEAR

If you're not familiar with the idea of 4K TV, it's a picture resolution four times more detailed than the 1080p resolution Blu-ray offers. The trouble is, if you do have £5,000 lying about for a 4K display, there still won't be much to watch on it. The Redray player hopes to fill this gap. Instead of using discs, Redray films will be distributed online, or delivered on small USB sticks.

Redray
Red.com, \$1,450 plus P&P (£904)



Listening to Music – the Benefits

There have been many studies carried out over the years that have shown remarkable benefits for mankind through listening to music. It is an activity that is intrinsic to all cultures and is one of the few that involves using the whole brain. Listening to music is now often used for various therapeutic purposes because it is believed to improve memory and intelligence, improve physical development and coordination, reduce stress and blood pressure, and even reduce levels of pain.

However, music can also be irritating if it's too loud or distorted, or if it distracts from other activities we are involved in. Most of the studies have been carried out using a reasonably good quality of musical reproduction. Quite remarkably, many people today and probably a majority of teens and late teens, are listening to a considerably lower quality level of music than their peers back in the 1970's. Back then a basic hi-fi system, often consisting of just a turntable, amplifier and a pair of speakers, was a 'must have'. Students going off to university would make it a priority to set themselves up with a decent hi-fi system – and the quality was, in retrospect, surprisingly good.

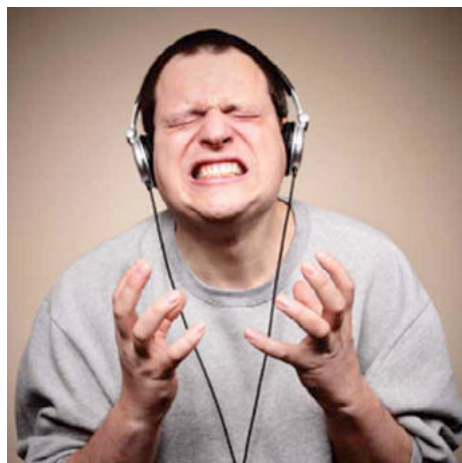


Quality vs Quantity

How different it is today where advances in technology have driven the desire for convenience and quantity at the considerable expense of quality. For many young people especially, the iPod, MP3 player or mobile telephone, connected to a pair of in-ear headphones, is their primary source of listening to music. The problem with this is that low-grade reproduced music is not going to deliver any significant beneficial outcomes for the listener. Probably the opposite will be true.

Style over substance?

Have advances in technology driven the desire for convenience and quantity at the expense of quality?



Low-grade music in this context is the result of two main factors, a) the delivery system (the hardware) and b) the source material (the 'music'). Although the amplification section of the mobile device is a technological wonder, it's not hi-fi! Nor are in-ear headphones. They can't hold a candle to the stereo-typical system from the 1970's. As far as the source material is concerned, it's being over-generous to call it music if it's a typical MP3 or AAC (the iTunes default format) download. These are both highly compressed formats with the most popular download speed of 128 kbps

being about one-eleventh the size of a full resolution CD track (1411 kbps), so the quality is inevitably far inferior. Information is irretrievably lost and the full dynamic range is lacking. Using an iPod while jogging does not really raise a quality issue but playing low-resolution tracks through, for example, an iPod docking station that feeds into a decent hi-fi system, is a disaster area.

It is very poor quality made louder and this even affects the type of music listened to. For example, most classical recordings downloaded as an MP3 or AAC file are a complete waste of time because there is so much information missing, all the complexities of the music are lost, and the recordings are reduced to just the essence of a tune.

Future of Recorded Music

If convenience has trumped quality for many people, we must ask what the future prospects are of maintaining

high quality music recordings. Fortunately audiophiles, or hi-fi connoisseurs, or perhaps most accurately described, music lovers, continue to drive the demand for quality because there are some wonderful hi-end systems available and being sold today. Another important reason for hope within the mass-market is that there is no longer any over-riding reason for MP3 and AAC to have such a following. These formats were designed to overcome very slow download speeds pre-broadband and expensive memory capacity. These are not significant factors for most people now. Even iPods, if loaded with full resolution tracks, can deliver acceptable results through a good system. The trade-off is a smaller selection of stored music. Full resolution audio streaming, as well as CD quality downloads, are already available and will become the norm as the wider public becomes aware of the tremendous quality benefit.



Audiophiles and Hi-Fi Connoisseurs

Hi-fi connoisseurs and audiophiles are very important to the music industry. By their nature, they are generally avid music lovers who enhance their enjoyment through listening to music at its very best quality level, which means playing great recordings through hi-end hi-fi to achieve the most outstanding results. Without them, the main driver for quality would probably be removed from the music industry.



Specialist Dealers

Specialist hi-fi retailers also come into this category because it's their interest that has driven them into their particular business. These specialist retailers also perform another very important function because, without them, hi-fi manufacturers would have to rely on the internet and hi-fi magazine reviewers to try and assess the relative merits of different brands for potential customers – a notoriously unreliable decision making process. Specialist hi-fi retailers are constantly being offered new products for assessment and potential stocking and, as it is also their hobby as well as their livelihood, they are greatly interested in achieving the best performance and seeking out the most outstanding combinations. More than that though is their relationship with audiophiles and hi-fi connoisseurs for, if they are to stay in business, they must satisfy the most discerning customers in the industry. The reality is that audiophiles and specialist hi-fi retailers (and the ones listed on this page represent the UK's finest) are essential to each other.

Specialist dealers know how to choose the products that combine as a superb system

and how to get the best out of it by expert installation in the home. They also appreciate how exciting and involving music can be and how it can deliver a powerful emotional experience. If there's a price premium over an internet purchase by choosing a specialist dealer, it's probably a small one, but it's unquestionably worth the difference.

Listed below is our selection of THE BEST HI-FI DEALERS IN THE UK.

They have been chosen because they are known to do an excellent job in guiding customers towards hi-fi that will give years of musical enjoyment and total satisfaction.

Our Top 20 UK Hi-Fi Dealers

SOUTH

Ashford, Kent
SOUNDCRAFT HI-FI
40 High Street.
t: 01233 624441
www.soundcrafthi-fi.com

Chelmsford
RAYLEIGH HI-FI SOUND & VISION
216 Moulsham Street.
t: 01245 265245
www.rayleighhi-fi.com

E. Grinstead
AUDIO DESIGNS
26 High Street.
t: 01342 328065
www.audiodesigns.co.uk

Kingston-upon-Thames
INFIDELITY
9 High Street,
Hampton Wick.
t: 020 8943 3530
www.infidelity.co.uk

Maidenhead
AUDIO VENUE
36 Queen Street.
t: 01628 633995
www.audiovenue.com

Norwich
MARTINS HI-FI
85-91 Ber Street.
t: 01603 627134
www.martinshi-fi.co.uk

Rayleigh
RAYLEIGH HI-FI
44a High Street.
t: 01268 779762
www.rayleighhi-fi.com

Southend-on-Sea
RAYLEIGH HI-FI SOUND & VISION
132/4 London Road.
t: 01702 435255
www.rayleighhi-fi.com

LONDON

Ealing
AUDIO VENUE
27 Bond Street.
t: 020 8567 8703
www.audiovenue.com

N1
GRAHAMS HI-FI
190a New North Road.
t: 020 7226 5500
www.grahams.co.uk

SW11
ORANGES & LEMONS
61/63 Webbs Road.
t: 020 7924 2043
www.oandlhi-fi.co.uk

W20
O'BRIEN HI-FI
60 Durham Road.
t: 020 8946 1528
www.obrienhi-fi.com

SOUTH WEST
Bath
AUDIENCE
14 Broad Street.
t: 01225 333310
www.audience.org.uk

Exeter
GULLIFORD HI-FI
97 Sidwell Street.
t: 01392 491194
www.gullifordhi-fi.co.uk

MIDLANDS
Banbury
OVERTURE
3 Church Lane.
t: 01295 272158
www.overture.co.uk

Birmingham
MUSIC MATTERS
363 Hagley Road,
Edgbaston.
t: 0121 429 2811
www.musicmatters.co.uk

Coventry
FRANK HARVEY
163 Spon Street.
t: 024 7652 5200
www.frankharvey.co.uk

Leicester
CYMBIOSIS
6 Hotel Street.
t: 0116 262 3754
www.cymbiosis.com

Nottingham
CASTLE SOUND & VISION
48/50 Maid Marian Way.
t: 0115 9584404
www.castlesoundvision.com

NORTH
Cheadle
THE AUDIO WORKS
14 Stockport Road.
t: 0161 428 7887
www.theaudioworks.co.uk

Chester
ACOUSTICA
17 Hoole Road.
t: 01244 344227
www.acoustica.co.uk

Hull
THE AUDIO ROOM
Savile Street, Hull
t: 01482 891375
www.theaudiroom.co.uk

York
SOUND ORGANISATION
2 Gillygate.
t: 01904 627108
www.soundorg.co.uk

These specialist dealers have been selected because they are known to do an excellent job in guiding customers towards hi-fi that will give years of musical enjoyment and total satisfaction.



STAR QUALITIES

VALUE FOR MONEY	★ ★ ★ ★ ★
SERVICE	★ ★ ★ ★ ★
FACILITIES	★ ★ ★ ★ ★
VERDICT	★ ★ ★ ★ ★

"I rely on **Wellman® tablets** every day, to help maintain the health and vitality that I need."

Mark Foster

Mark Foster
6x World Champion
8x World Record Holder



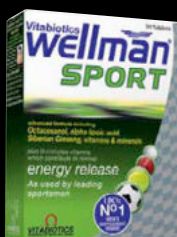
wellmān®

advanced nutrition just for men

Wellman® is an advanced range of nutritional products, tailored to the specific requirements of men. It has helped **6x World Champion Swimmer Mark Foster** so whether you're racing or not, why not see what it can do for you?



Original



Sport



50+



70+



Skin



Prostate®



Boost

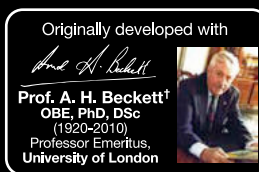


Drink

www.wellman.co.uk

From Boots, Superdrug, supermarkets, Holland & Barrett, GNC, Lloydspharmacy, pharmacies & health stores.

Vitamin supplements may benefit those with nutritionally inadequate diets. † Professor Beckett is not cited in the capacity of a health professional, but as a product inventor and former Chairman of Vitabiotics.



VITABIOTICS
SCIENCE OF HEALTHY LIVING



ULTIMATE TEST

LYTRO, CAMERA, ACTION!

This camera could change photography as we know it. It doesn't take photos, it captures 'light fields'. **Sam Kiildsen** gets to grips with the Lytro camera to see if it lives up to the hype →



ILLUSTRATOR: MAGICTORCH

The Lytro may look fairly unassuming, but it could represent the biggest step in photography since the advent of digital cameras.

The world's first commercially available light field camera, it takes images in a totally different way from standard snappers.

The technology, which has been in development at California's Stanford University since the 1990s, uses a sensor packed with millions of micro lenses to capture all the light rays in a scene. Traditional cameras capture these rays as a single, fixed amount of light, but Lytro stores everything – colour, intensity and direction – to create what its makers call a 'living' picture. Coupled with the built-in software, this means the user can change what's in focus *after* a shot is taken. With the Lytro, gone are the days of shooting a portrait only to find the tree behind Granny is nice and sharp while her face is all blurry.

That the company has managed to cram this cutting edge technology – which once required the use of a supercomputer – into a pocket-sized product is some achievement, but the design of the lens and sensor strongly impacts upon the camera's shape. Unlike most models, the Lytro is longer than it is wide, and as a result sits a little strangely in the hand.

SCREEN TEST

The glass-covered touchscreen at the front is used to frame shots, view them in the Living Photo mode and tinker with settings. In other words, it's important. So we were more than a little disappointed with its tiny size (3.8cm, or 1.5 inches) and low pixel count. The former makes tapping the on-screen options awkward, while the latter leaves everything looking jagged and rough. It's so small and unclear that you barely even notice the changes in focus you can make with Lytro technology. There's real room for improvement here, and it's something we'd hope to see addressed in the next model.

The zoom slider, a touch-sensitive control to adjust the lens's zoom, is also problematic.

CAMERA FUTURA

Find your way around the Lytro camera

Aluminium body

The Lytro boasts a sturdy but lightweight aluminium shell that seems more than a little Apple-inspired. It's available in a choice of five colours.

Grip and zoom slider

The rubbery grip helps you shoot one-handed without too much bother, and features a touch-sensitive slider on top that controls the zoom.

Screen

The glass screen is just 3.8cm in size and irritatingly low on pixels, but the touch controls work well. Sliding your finger to the right while in shooting mode opens up the viewer, letting you browse through your shots.

USB port

The micro USB port on the bottom of the camera handles two duties: charging the battery and moving files around. There's either 8GB or 16GB of storage, too – enough for around 350 or 750 shots, respectively.

Lens

As well as an 8x optical zoom, the Lytro's lens features a constant f/2 aperture. That's wide enough to take usable shots in low light, but with no flash onboard, don't expect miracles in the dark.

It's set on the top of the camera, within the rubber grip, and is all too easy to touch – and change – by mistake. The zoom itself is a welcome feature, though: being optical, it retains full resolution throughout its entire range. While 8x zoom isn't a huge amount, it's handy for getting closer to far-off subjects, as well as shooting portraits while keeping the background slightly out of focus.

Taking a shot couldn't really be simpler. You just compose your image using the screen and hit the shutter button. Because the Lytro

captures *everything* in focus, there's no need for autofocus at all and the shot is taken instantly.

As for the shots themselves, after the initial excitement of playing with a brand new technology, we have to admit to being a tad disappointed. At this stage in its development, light field technology delivers shots that are surprisingly, almost shockingly low resolution. When viewed as simple JPEG images, these square photos resemble those taken on a cheap phone camera about five years ago: muddy, lacking

in resolution and with the pixel structure clearly visible. If you're looking for photos that can be blown up and mounted on the wall, the Lytro is not for you. And there's no video option at all.

However, 'normal' photos aren't what the camera is about. It's more concerned with showing off its 'living photos' – shots that can be changed and altered extensively after being taken. You can do this either on the camera itself (although that low-res screen makes this near impossible) or by uploading the

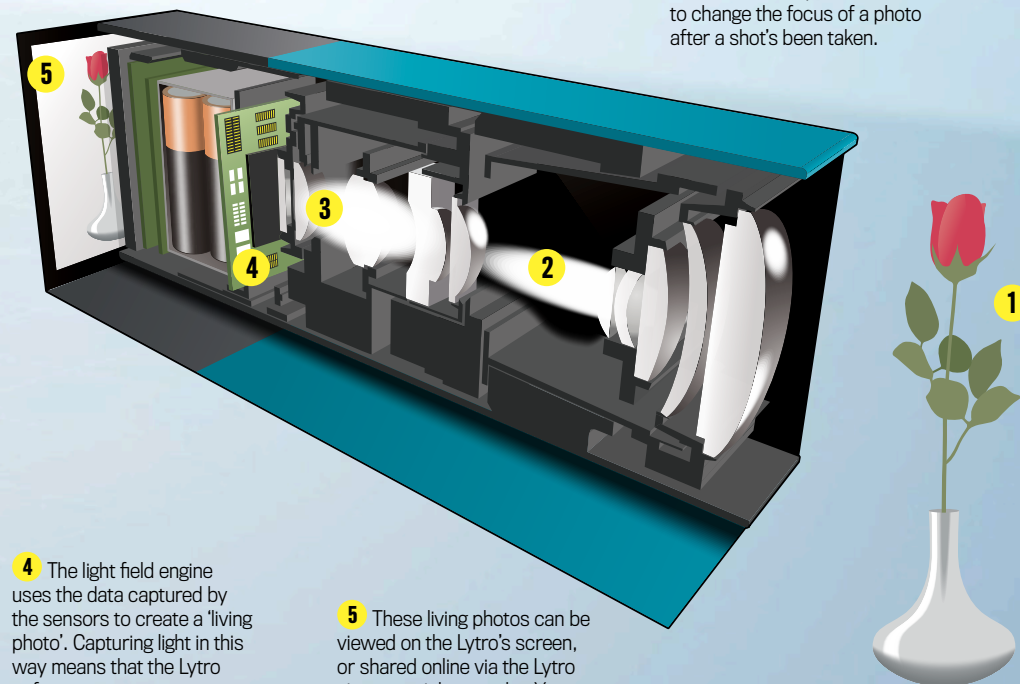
HOW IT WORKS

The technology that captures your 'living photos'

1 Light from the outside world enters the Lytro's outer lens, which has a constant f/2 aperture. In other words, it lets a lot of light in, to capture as much information as possible.

2 Between the light entering the camera and hitting the sensor at the back, the light is bounced around a series of lenses to create a 'light field'.

3 The light from this field then hits an array of thousands of microlenses placed in front of a sensor that records the colour, intensity and direction of individual rays hitting it (11 million of them). It's this data that allows the Lytro software to change the focus of a photo after a shot's been taken.



4 The light field engine uses the data captured by the sensors to create a 'living photo'. Capturing light in this way means that the Lytro software can reprocess an image after it's been taken: to change what's in focus or to shift the perspective slightly.

5 These living photos can be viewed on the Lytro's screen, or shared online via the Lytro site or social networks. You can also export them as JPEGs, but you'll lose the ability to play around with the light field.

FIX UP, LOOK SHARP

Lytro's refocusing abilities in action

Lytro works particularly well with portraits and close-ups. Below, 'A' have the background in focus, but can be changed to put the foreground in focus (B).



photo to your computer (both Windows and Mac machines are supported), using Lytro's own software and playing around with them there. Shots can also be shared on Lytro.com, allowing anybody to adjust them.

While we tested the camera, all we could do was alter the point of focus in a scene (for example focusing on a subject in the foreground, leaving the background out of focus, and vice versa), but soon the people behind Lytro hope to expand the camera's possibilities. We're told

there will be 'Living Filters', which offer Instagram-style colour-editing with more interactivity, and 'Perspective Shift', which will allow you to slightly change the point-of-view of a shot after you've taken it, giving photos a 3D feel. The latter again stretches the boundaries of what's possible with a digital camera – it's a thoroughly impressive concept.

PICTURE IMPERFECT

In fact, that last sentence pretty much sums up our feelings towards the Lytro camera. The

technology is impressive, but the current product isn't. Light field technology seems to us as though it will have a part in the future of digital photography – sports photographers and photojournalists will never need to worry about poor focus ruining an otherwise perfect image – but at present the shots are too low-res to be truly stunning. The living photos are exciting to play with, and they'll certainly wow your friends, but they're too small to prove practically useful. Add to this the tiny, low-res screen

and slightly odd design, and the Lytro feels like an expensive proof-of-concept rather than an appealing product – a little like the first generation of commercially available digital cameras, which were huge, pricey and turned out weak photos. But we'll be watching intently to see what the company comes up with next, because we're certain that light field tech is here to stay.

Lytro

From \$399 (£250) plus P&P online
Info: Lytro.com



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Q&A

YOUR QUESTIONS ANSWERED

BY OUR EXPERT PANEL



SUSAN BLACKMORE

Susan is a visiting psychology professor at the University of Plymouth. Her books include *The Meme Machine*



DR ALASTAIR GUNN

Alastair is a radio astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester



ROBERT MATTHEWS

After studying physics at Oxford, Robert became a science writer. He's a visiting reader in science at Aston University



GARETH MITCHELL

Starting out as a broadcast engineer, Gareth now writes and presents *Digital Planet* on the BBC World Service



LUIS VILLAZON

Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*

EMAIL YOUR QUESTIONS TO questions@sciencefocus.com

or post to *Focus* Q&A, Tower House, Fairfax Street, Bristol, BS1 3BN

The booming city of Dubai is one of the most power-hungry on the planet



Q JOANNA TAYLOR, SALISBURY

How much power do the biggest cities use?

A LONDON, WITH A population of around 8 million, uses electrical power at an average rate equivalent to the output of around five nuclear power stations. But size isn't everything. Dubai, where temperatures regularly reach over 40°C, is home to some of the most power-hungry people in the world. They consume it at a rate equivalent to the output of four nuclear power stations – while having barely one-quarter the population of London. **RM**

Q CLAIRE WATERS, LOUGHBOROUGH

What is the fastest-spinning star ever found?



An artist's impression of the superfast-spinning star VFTS 102

A A HOT BLUE star, 25 times the mass of the Sun, is the fastest-spinning star known. Called VFTS 102, it resides within the Tarantula Nebula. At its surface, the star rotates at about 600km/s (more than 1 million mph) – so fast that it is almost, but not quite, flinging itself apart. The origins of this fast rotation are not yet clear, but it's likely that VFTS 102 was once part of a binary star system and was 'spun up' due to the transfer of mass from its now dead companion.

Although VFTS 102 is the fastest rotating 'normal' star, pulsars actually spin more quickly. Pulsars are the collapsed cores of stars that became supernovae. The fastest spinning pulsar yet discovered is known as Ter5ad. It rotates 716 times every second, which means the rotation speed at its equator is 70,000km/s – that's about 158 million mph, or roughly 24 per cent of the speed of light. **AG**

In Numbers

630,000

The number of solar panels to be installed by 2014 as part of Africa's largest solar power farm, based in Ghana

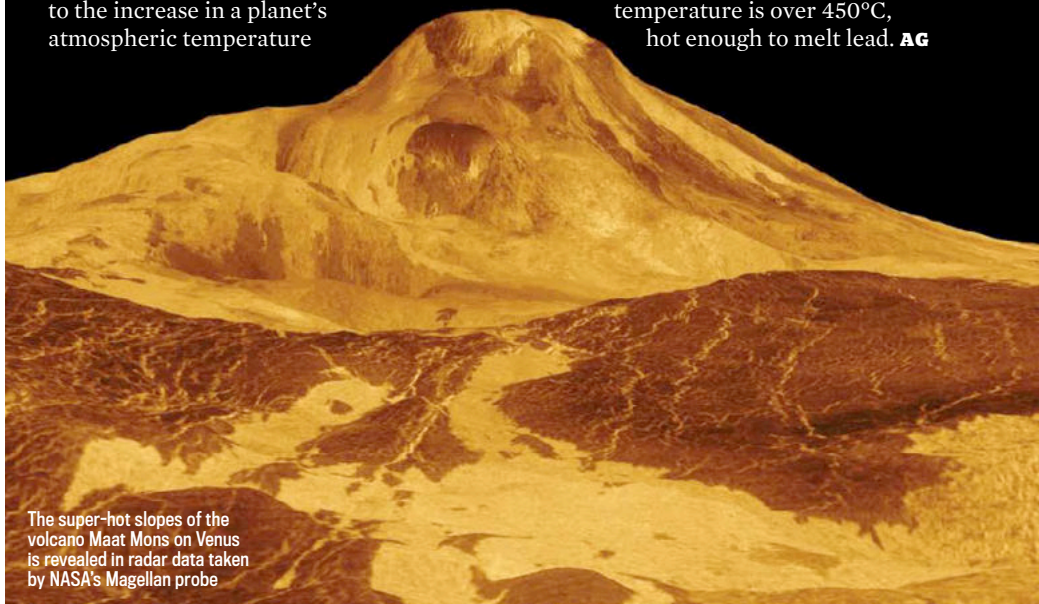
Q JAMES SHORT, FARNBOROUGH

Have any planets other than Earth showed signs of global warming?

A 'GLOBAL WARMING' IS a term applied to the rise in the mean temperature of the Earth's atmosphere over the last century or so. The term is only ever applied to Earth because it specifically refers to the perceived effect of human activities such as burning fossil fuels. However, other planets do show evidence of the 'greenhouse effect', of which global warming is an example. The greenhouse effect refers to the increase in a planet's atmospheric temperature

due to the presence of gases such as carbon dioxide, water vapour, methane and ozone. The planet Mars and one of Saturn's moons, Titan, both have small greenhouse effects, but by far the largest greenhouse effect in the Solar System is that of Venus. The Venusian atmosphere is 50 times as dense as Earth's and consists almost entirely of carbon dioxide, a very effective greenhouse gas.

This means Venus's mean surface temperature is over 450°C, hot enough to melt lead. **AG**



The super-hot slopes of the volcano Maat Mons on Venus is revealed in radar data taken by NASA's Magellan probe

Q JOSEPH TING, AUSTRALIA

What health risks have been linked to Wi-Fi?

A WI-FI IS BASED on radio waves whose frequency is similar to that of microwaves. And given what microwave ovens can do to, say, chicken nuggets, it's perhaps not surprising that there's been concern that exposure to Wi-Fi could be unhealthy. Fortunately, however, while they're pretty ubiquitous, Wi-Fi waves are emitted at far lower intensities than microwaves in ovens. As a result,



they can't produce anything like the same heating effect.

Even so, some people still worry that perhaps even this far weaker effect could cause damage after years of exposure. To date, epidemiologists have failed to uncover any consistent evidence for even long-term effects. It does, however, suggest that the health effects, if there are any, are pretty weak, and that we should worry about more hazardous things – like tripping over all the cables we'd need if we didn't use Wi-Fi devices. **LV**

QUESTION OF THE MONTH

Q ALEX LESTER, ST ALBANS

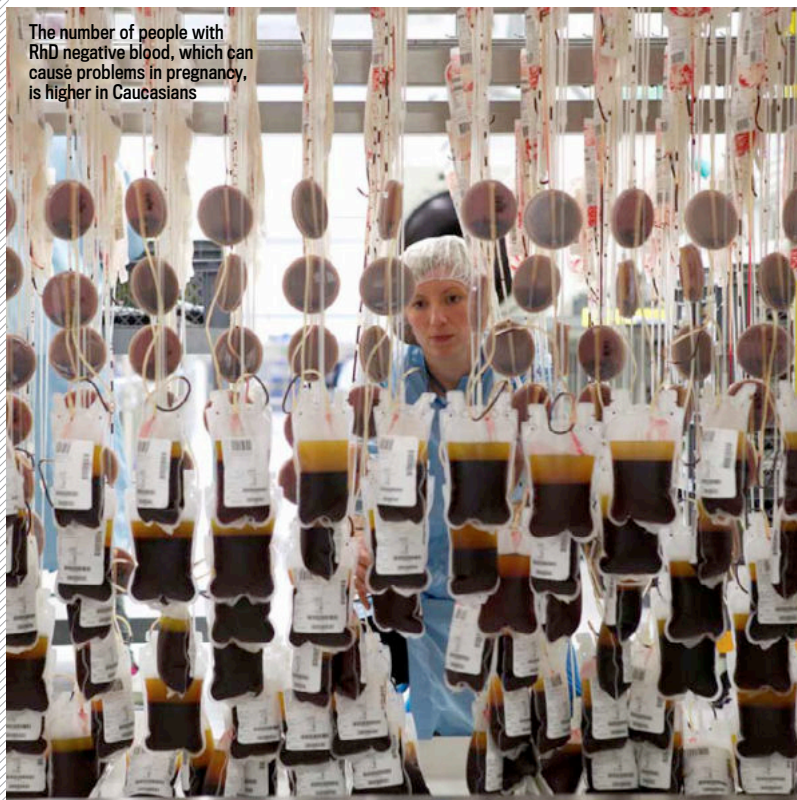
Why has the rhesus negative problem in pregnancy not been eliminated by natural selection?

A THIS PROBLEM OCCURS when the blood types of a mother and her foetus are incompatible, for example, when the mother is RhD negative and the foetus RhD positive. Unless treatment is given, the foetus suffers from a haemolytic disease of the new-born (haemolytic means destruction of the blood) called erythroblastosis fetalis, in which its red blood cells fail.

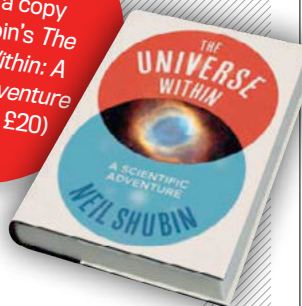
The proportion of RhD negative genes varies between populations: it is rare in East

Asians, South Americans and Africans, but more common in Caucasians. So the question is why this gene has survived at all. The answer may be that it partially protects people against a parasitic disease called toxoplasmosis that is carried by cats and is latent in as much as one-third of the human population. If this is correct it would explain the variations around the world, since different countries have widely different levels of contact with cats. **SB**

The number of people with RhD negative blood, which can cause problems in pregnancy, is higher in Caucasians


WINNER!

Alex wins a copy of Neil Shubin's *The Universe Within: A Scientific Adventure* (Allen Lane, £20)



You need a pair of these to handle highly radioactive elements

Q GEORGE BRYDON, BRIGHTON

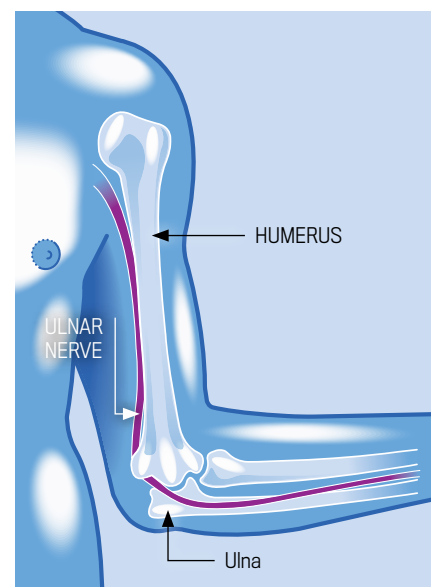
What makes an element radioactive?

A RADIOACTIVITY IS THE result of the break-up of atomic nuclei. These consist of positively charged protons that repel each other, 'glued' together by uncharged neutrons. Neutrons and protons can spontaneously change into other particles and the resulting loss of 'glue' triggers nuclear disintegration and radioactivity. **RM**

Q DAVIDE FRANCIA, ITALY

What is a funny bone?

A IT'S ACTUALLY A nerve, rather than a bone. The ulnar nerve runs along the inside edge of your arm and isn't protected by muscle or bone. If you hit your elbow just so, you can trap the nerve between the skin and the humerus (upper arm bone), causing shooting sensations down to your little finger. **LV**



TOP TEN

FASTEST SUPERCOMPUTERS



1. Titan

USA

Test speed: 17.59 petaflops
Theoretical peak speed:
27.11 petaflops



2. Sequoia

USA

Test speed: 16.32 petaflops
Theoretical peak speed:
20.13 petaflops



3. K computer

Japan

Test speed: 10.51 petaflops
Theoretical peak speed:
11.28 petaflops



4. Mira

USA

Test speed: 8.16 petaflops
Theoretical peak speed:
10.07 petaflops



5. JuQUEEN

Germany

Test speed: 4.14 petaflops
Theoretical peak speed:
5.03 petaflops



6. SuperMUC

Germany

Test speed: 2.9 petaflops
Theoretical peak speed:
3.18 petaflops



7. Stampede

USA

Test speed: 2.66 petaflops
Theoretical peak speed:
3.96 petaflops



8. Tianhe-1A

China

Test speed: 2.57 petaflops
Theoretical peak speed:
4.7 petaflops



9. Fermi

Italy

Test speed: 1.72 petaflops
Theoretical peak speed:
2.1 petaflops



10. DARPA trial subset

USA

Test speed: 1.51 petaflops
Theoretical peak speed:
1.94 petaflops

Q MARY CROFT, POOLE

What would happen if all the coral reefs disappeared?

A OUR PLANET WOULD be a different place. In the 1950s, when research began, many coral reefs were thriving but since then about 20 per cent have been lost through increasing sea temperatures and acidification.

Reefs are built by tiny organisms called corals and are home to about a quarter of all marine species, even though they cover only 0.1 per cent of the oceans. If they all disappeared tomorrow, an entire ecosystem would be lost, drastically reducing our planet's

biodiversity. For humans, coral reefs provide abundant fishing resources, as well as protection for some low-lying islands and lucrative tourist destinations. About 850 million people live within 100km of a reef, of whom about a third depend on it for their food or livelihood.

If the sea temperature and acidity were favourable the day after tomorrow, then the reefs would quickly begin to grow back, but if climate change continues they might never do so. **SB**



The rich biodiversity of coral reefs could be lost forever if sea temperatures continue to rise

Q JOHN PEARSON, SPAIN

Why is the Universe made up of galaxies and not just random stars?



Galaxies are due to fluctuations in the density of the primordial Universe

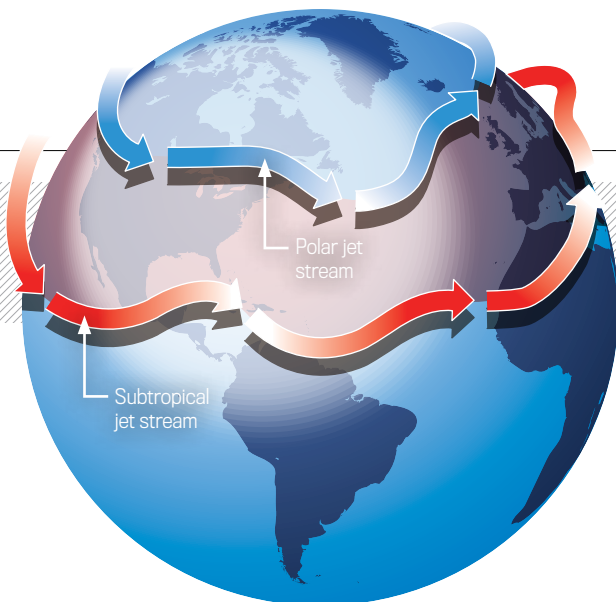
A THIS IS A consequence of the fine-scale structure of matter and energy in the very early Universe. Although the formation of structure in the Universe is not fully understood at present, astronomers believe that minute fluctuations in the density of material in the primordial Universe became the seeds for the formation of proto-galaxies and clusters.

Stars eventually formed from collapsing clouds within those proto-galaxies. So it is likely that galaxies exist (rather than a random distribution of stars) simply because those primordial fluctuations were of the right scale to create them. **AG**

Q JOSEPH VENABLES,
WEST CHESHIRE

Is it faster to fly east or west?

A IT'S FASTER TO fly east because of the jet streams. These are high-altitude air currents that circle the globe at 160 to 480km/h (100 to 300mph). Each hemisphere has a polar jet and a subtropical jet, and all of them circulate eastwards. The jets are only a couple of miles wide and don't take the shortest route across the ocean, but it's still worthwhile for commercial flights to fly within them when flying west to east. When flying westwards they take



Each hemisphere has a polar and subtropical jet stream

a more direct route that avoids flying against the jet stream. The difference can be two hours' flight time on a transatlantic flight.

Spacecraft are also launched into an eastwards orbit, but for a different reason. Orbital speed is relative to the centre of the Earth, rather than the speed over the ground. By launching to the east, they can add the rotational speed of the Earth to their own orbital speed. **LV**

Q BEN GOODWIN, LEWES

If everyone stood together what area would we cover?



A LET'S SUPPOSE we give each person the same space they would have if they were lying in a coffin, except we'll stand the coffins on their end.

A medium sized coffin has an internal cross section of 520 by 290mm. That's seven billion people, each occupying 0.15m². You could pack them together in just 1,050km² (260,000 acres).

They wouldn't quite fit on the mainland of Shetland, but there would be room for three times that many on the Isle of Wight. Actually getting them there is another matter: running all three ferries round the clock, it would take 432 years to transport everyone across the Solent! **LV**

WHAT IS THIS?



KNOW THE ANSWER?

Go to sciencefocus.com/qanda/what and submit your answer now!

LAST MONTH'S ANSWER:

Granules of sand; well done to Richard Territt who answered correctly.

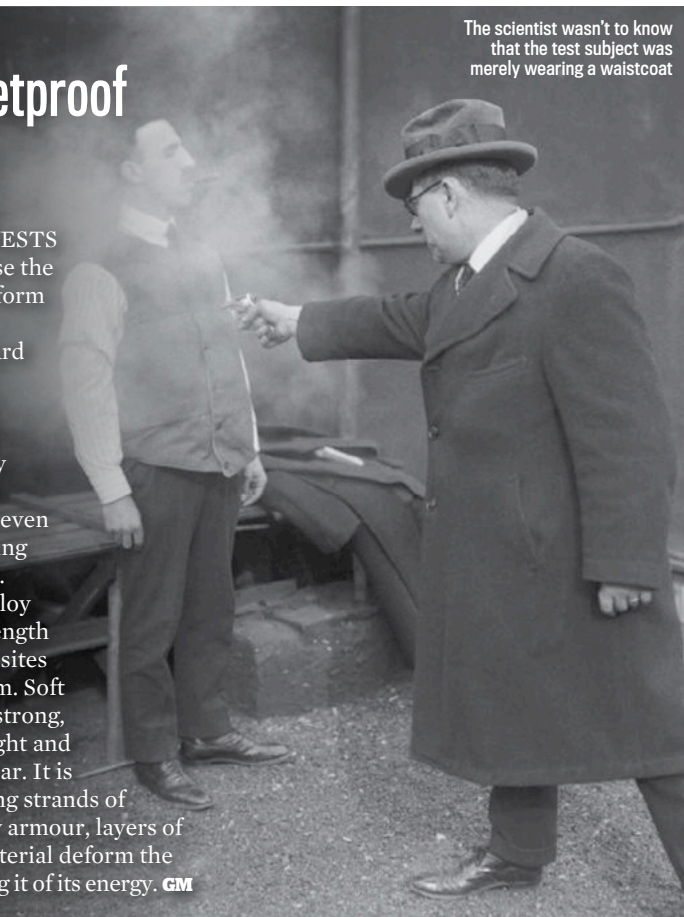
Q JAMES KING, EXETER

How do bulletproof vests work?

A BULLETPROOF VESTS are designed to disperse the round's energy and deform the slug to minimise blunt force trauma. Hard body armour is made of strengthened steel plates. It is strong and effective but also heavy and cumbersome. But some ammunition can even penetrate steel, requiring stronger materials still.

The latest vests employ overlapping super-strength but lightweight composites of ceramic and titanium. Soft body armour is not as strong, but it is more lightweight and less conspicuous to wear. It is woven out of interlacing strands of Kevlar. Like hard body armour, layers of this tough, net-like material deform the incoming bullet, robbing it of its energy. **GM**

The scientist wasn't to know that the test subject was merely wearing a waistcoat



Q LUIGI SEBASTIANO, WORTHING

Has a child ever been conceived in space?

A NO-ONE has ever had sex in space, much less got themselves pregnant, according to both NASA and the Russian

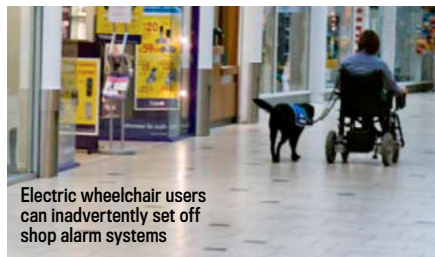


Space Agency. Spacecraft are crowded and cramped, with virtually no privacy. Astronauts are regarded as on duty 24-hours a day and would be unlikely to risk their privileged flight status with this sort of unsanctioned behaviour. **LV**

Q SPENCER MEAD, CHELTENHAM

Why do electric wheelchairs set off store alarms?

A THE MOST LIKELY explanation relates to store alarms triggered by small radio frequency tags stuck on to products. The tags contain a coiled antenna activated by radio waves from a transmitter near the shop's exit. A nearby receiver detects the signal from the tag, setting off the alarm. It is possible that the wheelchair's electronics contain coils that happen to resonate at a similar frequency to that of the store alarm. **GM**



Electric wheelchair users can inadvertently set off shop alarm systems

In Numbers

62,500

kilograms (62.5 tonnes) is the weight of the heaviest armoured vehicle. Called Titan, it's a British bridge-laying tank.

Q KEVIN MCGRATH, BY EMAIL

Do ants have feelings?



It's lucky that ants don't experience annoyance at overcrowding

A ANTS DON'T HAVE complex emotions such as love, anger, or empathy, but they do approach things they find pleasant and avoid the unpleasant. They can smell with their antennae, and so follow trails, find food and recognise their own colony. Their exoskeleton has sensory hairs on the outside but they probably cannot feel

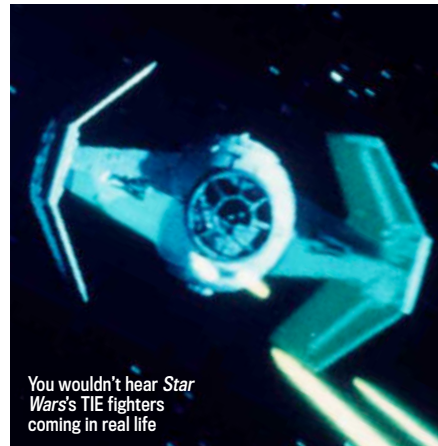
damage on the inside, which is why parasites can destroy them if they can get in without touching the sensors.

Each ant's brain is simple, containing about 250,000 neurones, compared with a human's billions. Yet a colony of ants has a collective brain as large as many mammals'. Some have speculated that a whole colony could have feelings. **SB**

Q SIMON DOVEY, BRAINTREE

At what height is the air too thin to carry sound waves?

A AS SOUND IS wave-like changes in the concentration of molecules, it can exist even in the supposed 'vacuum' of space – which is never truly devoid of all matter. That said, sound does get harder to hear the thinner the air, so you'd have to be very close to, say, an exploding spaceship to hear it explode. **RM**



You wouldn't hear Star Wars's TIE fighters coming in real life



HOW IT WORKS

WORLD'S TALLEST BUILDING

WHEN IT'S COMPLETE the Chinese skyscraper Sky City will be the tallest structure on the planet, but this isn't the behemoth's most remarkable fact. The current tallest building in the world, the 829.8m-high Burj Khalifa in Dubai, took six years to build; China wants to throw up a building nearly twice as high as the Empire State Building in just three months!

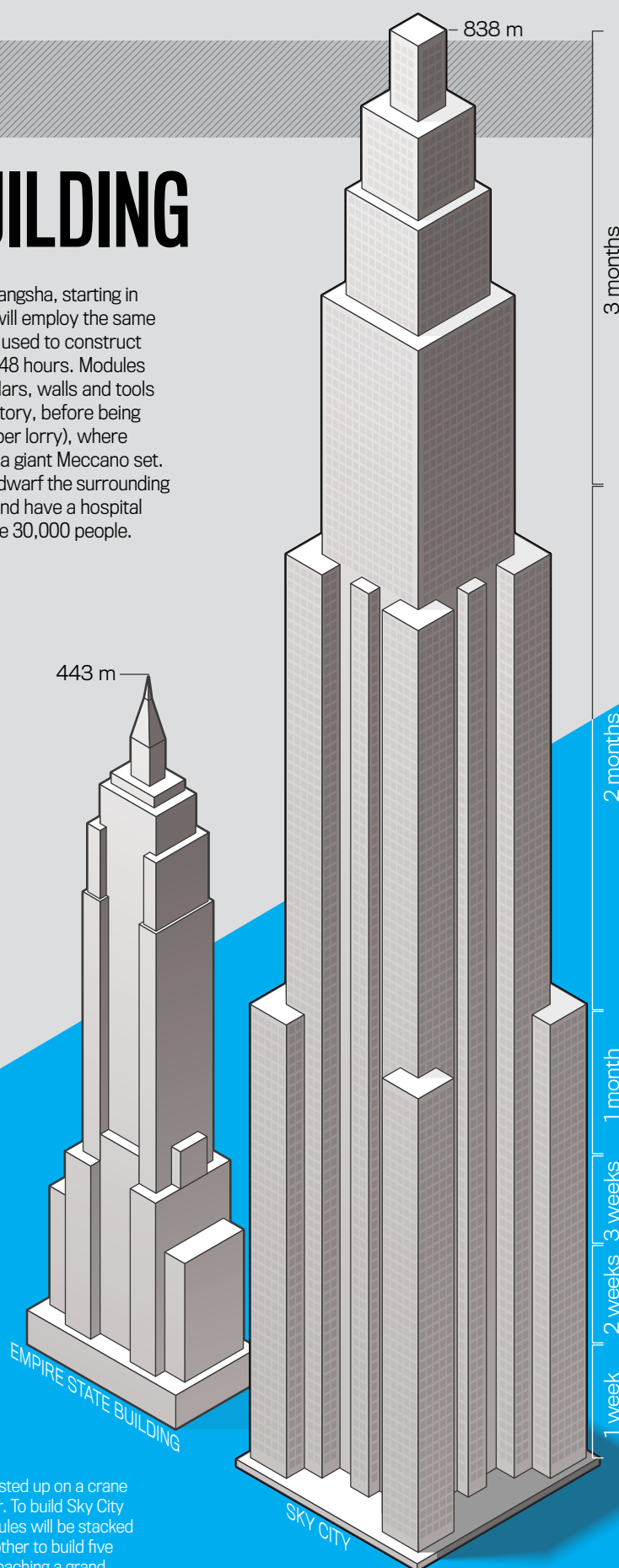
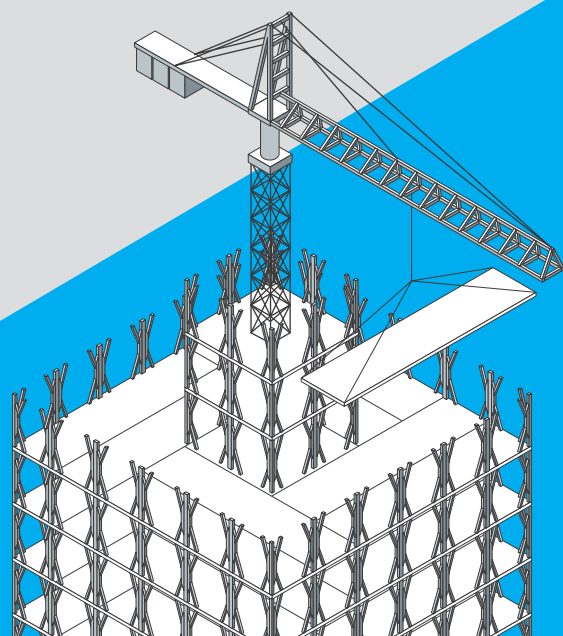
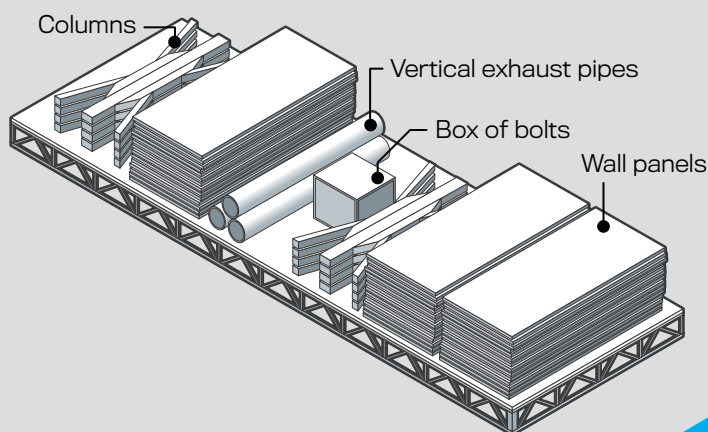
The feat is being attempted by Broad Sustainable Building, which will erect

Sky City in the city of Changsha, starting in January. The company will employ the same techniques it previously used to construct a 15-storey hotel in just 48 hours. Modules containing the floors, pillars, walls and tools are put together in a factory, before being carried to the site (two per lorry), where they're put together like a giant Meccano set.

Once complete, it will dwarf the surrounding buildings at 838m high and have a hospital and apartments to house 30,000 people.

FLAT-PACKED SKYSCRAPER

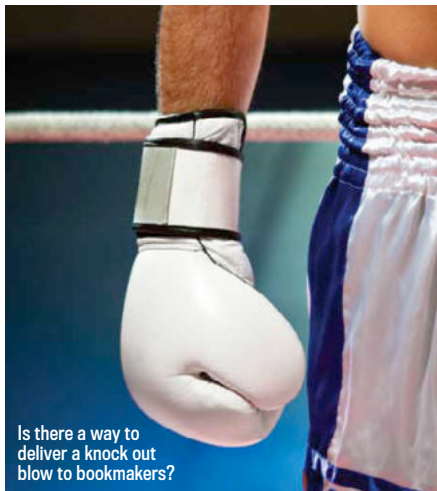
A module consists of a floor section with flat-packed walls and the columns needed to support another module placed on top. Plus bolts that stick it all together.



Modules are hoisted up on a crane and put together. To build Sky City in 90 days, modules will be stacked on top of each other to build five storeys a day, reaching a grand height of 220 storeys

Q SIMON BLAKE, TONBRIDGE

Can you use two bets to guarantee a win?



Is there a way to deliver a knock out blow to bookmakers?

A YES, ALTHOUGH – AS in everything to do with gambling – a win can't always be guaranteed. The trick lies in something called arbitrage, or 'arbing', which exploits differences in the odds offered by different bookmakers for the same event. To take a (very) simple example, imagine a contest between two boxers Abe and Bob. If draws aren't allowed, the bookies can offer odds on the only two possible outcomes: Abe wins, or Bob wins. These odds reflect the bookies' estimates of the probabilities of these two outcomes, but unlike true probabilities, they always add up to more than 100 per cent – as they include the bookie's profit margin. That rules out making money by backing both Abe and Bob to win with any one bookie.

But the odds offered by different bookies may differ slightly, and this opens up the possibility of backing Abe with one bookie, and Bob with another – locking in a profit, regardless of the outcome. Such 'arbs' exist, but the difference in bookies' odds is usually tiny, so big stakes have to be put on with each bookie to make a decent return. And if the odds change when you're doing all this, the 'arb' can vanish – leaving you out of pocket. **RM**

Did you know?

The Pirahã tribe who live in the Amazon rainforest have no words for numbers, which means they are unable to count.



Flying in a 'V' formation helps birds save energy during long flights

Q FAUSTO STELLA, THAILAND

Why do birds never crash into each other when flying in groups?

A MANY LARGE BIRDS, such as geese and pelicans, fly in a V-formation, or echelon, both to improve flight efficiency and to avoid collisions. Drag is reduced by as much as 65 percent, and range can be increased by over 70 per cent because each bird flies in the upwash from the wing tip vortex of the one in front and uses its updraft. Only the leading bird fails to benefit, but the other birds in the flock shift around in the group to share the burden. In fact echelons are rarely perfect Vs and more often are J shapes.

In either shape, each bird gets the best possible view of the bird in front so that it can maintain a safe distance and so avoid colliding.

Smaller birds gain less advantage from flying in these shapes and fly in looser groups. When we watch them it seems miraculous that they don't collide, but their visual system works much faster than ours, just as their metabolism and muscles do. Speeded-up films of people walking in crowded streets can appear just as miraculous. **SB**

Q ADAM DOOLEY, MANCHESTER

Why do we have fingerprints?

A FINGERPRINTS DEVELOP between the second and sixth months of pregnancy. The middle layer of the skin on the pads of the fingers begins to grow faster than the inner and outer layers, and this causes the skin to buckle into ridges. The exact pattern of those ridges is determined by the composition of the amniotic fluid and by the way that the foetus touches things as it moves around. Fingerprints have

long been thought to improve grip, but a 2009 study at the University of Manchester found that fingerprints actually reduce grip slightly on smooth surfaces. They might still provide increased grip on rough surfaces, but we don't have prints on the palms of our hands, so it's unlikely



that this is their primary function. Rather, they improve our touch sensitivity by amplifying tiny vibrations as our fingers brush against a surface. **LV**

THE NIGHT SKY: WHAT CAN I SEE IN FEBRUARY?

BBC ONE

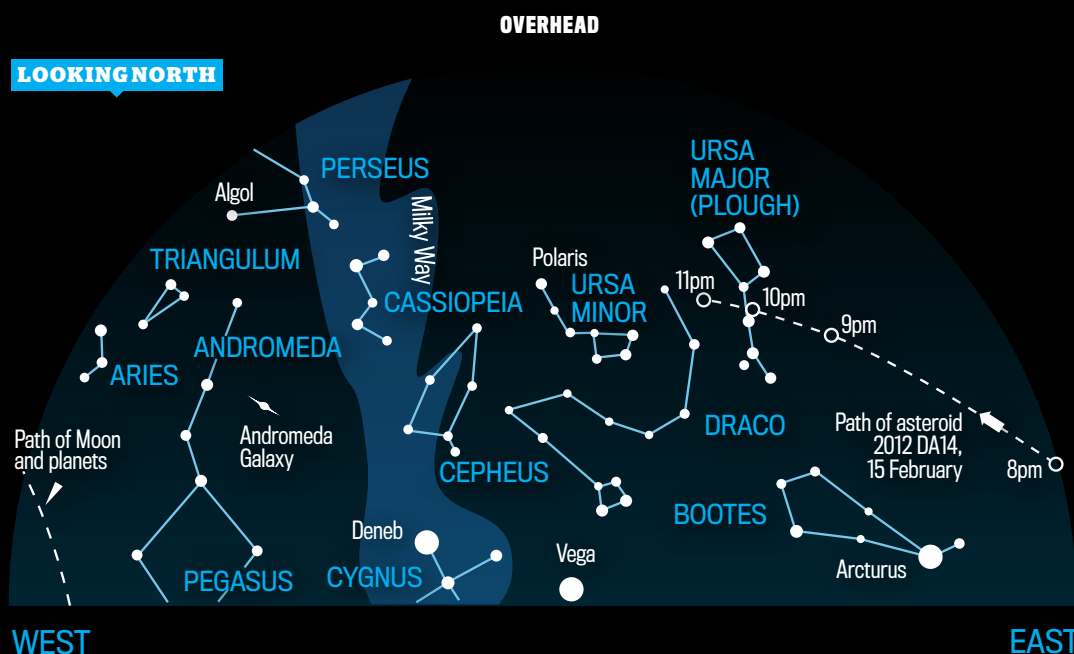
Don't miss *The Sky At Night* on BBC One every month
www.bbc.co.uk/skyatnight

Astronomy with
Heather Couper
and Nigel Henbest



THE WINTER STARS are still strutting their stuff across February's dark skies. Yellow-white Capella lords it overhead, while the brilliant stars of Orion – slipping to the west – are still looking spectacular. It's the last really good chance to see Orion's Nebula (located below his 'Belt' of three stars), so whip out those binoculars! And scintillating Sirius – the brightest star in the sky – soars high in the south. Planet-wise, brilliant Jupiter is still in charge, while ring world Saturn joins the stage at midnight, rising in the southeast.

LOOKING NORTH



LOOKING NORTH

15 February, 7.25pm

Asteroid 2012 DA14 swings past Earth tonight at a distance of 28,000km – that's closer than the orbits of geostationary satellites. It will be fast-moving, but should be visible through binoculars. And it won't collide with the Earth!

18 February, 10pm

The star Algol in Perseus means 'the winking demon' in Arabic – so Persian astronomers knew that there was something odd about the beast. And tonight you'll see why: Algol is just a third of its normal brightness – a result of a cooler, less luminous companion star passing in front of it.

LOOKING SOUTH

All month, 10pm

Next to the famous twin stars of Gemini – Castor and Pollux – is a faint celestial gem, Praesepe. The group of around 1,000 stars is nicknamed the 'Beehive Cluster'. Just visible to the unaided eye, it is a beautiful sight through a pair of binoculars.

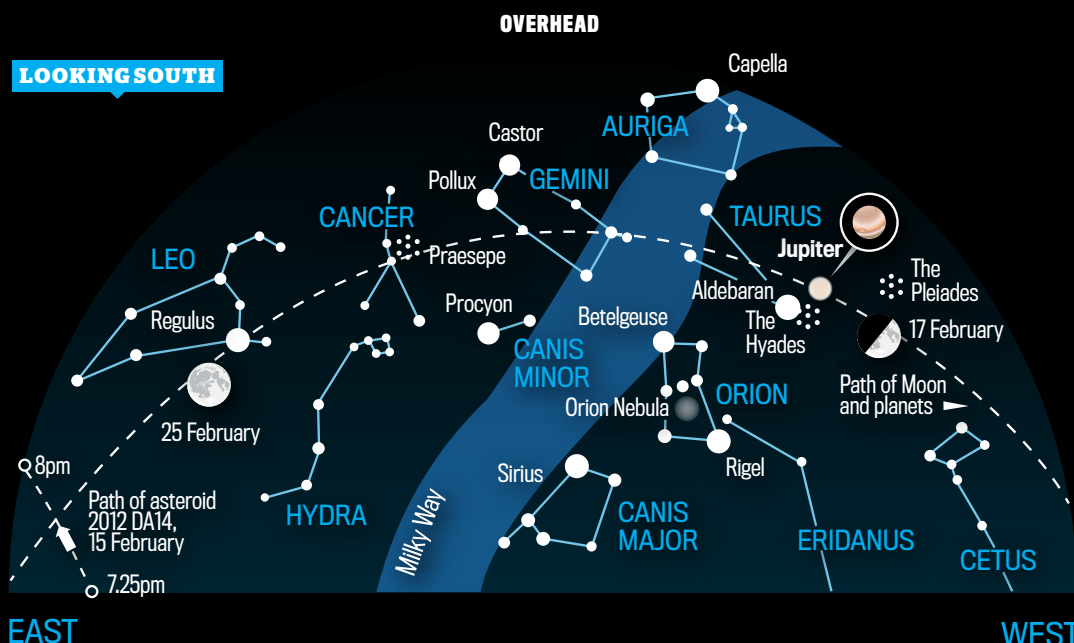
11 February, just after sunset

The slender crescent Moon gets up close and personal with the innermost planet Mercury. It will be a pretty grouping, with the winged messenger placed to the lower left of the Moon. A great chance to locate elusive Mercury!

16 February, around 6.30pm

Having located Mercury, spot the planet without the glare of the Moon. The tiny world is putting on its best performance of the year today, setting nearly two hours after the Sun.

LOOKING SOUTH



Find out more

Sky At Night Magazine
On sale now, priced £4.75

Q CLAUDE PARET, TWICKENHAM

Could a tree grow in zero-g?

A NORMAL PLANT GROWTH relies on gravity to provide a direction indicator. Tiny starch particles settle at the bottom of cells called statocytes to signal the plant to produce more of the hormone auxin at that end. This is what tells roots to grow downward and shoots to grow upward. Without gravity, the

shoots just grow towards water, instead of breaking free into the air, and they quickly go mouldy. With careful teasing though, they can be encouraged to grow in the right shape. Because of the very limited space available on the International Space Station, nothing larger than a pea plant has been grown in space yet. Five species of tree have been grown on Earth, from seeds that flew around the Moon on Apollo 14, but we still don't know exactly what effect prolonged zero-g conditions would have on tree growth. **LV**



A zucchini plant grows on the International Space Station in a special bag

Q RICHARD O'NEILL, GLASGOW

Why don't we have eyes in the back of our heads?

A FOR OUR FOUR-legged ancestors, this wouldn't have been useful because the body blocks your view. It's better to have side-mounted eyes with a wide field of view, as many grazing animals do. But this comes at the expense of good binocular vision for judging speed and distance, which is important if you are a hunter or swing from the trees. Now that we walk upright, extra eyes might be handy, but we've only been bipedal for 4 million years, which isn't long enough for them to have evolved. **LV**

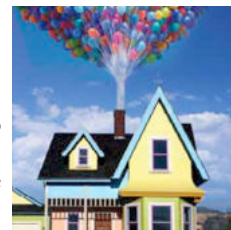


An extra set of eyes would help this proboscis monkey judge speed and distance

Q MATT ROGERS, LONDON

How much would it cost to launch a three-bed house into space?

A A BRICK house would be impossible to lift into space. Brick and cement are too brittle and the house would shake itself to rubble during the launch.



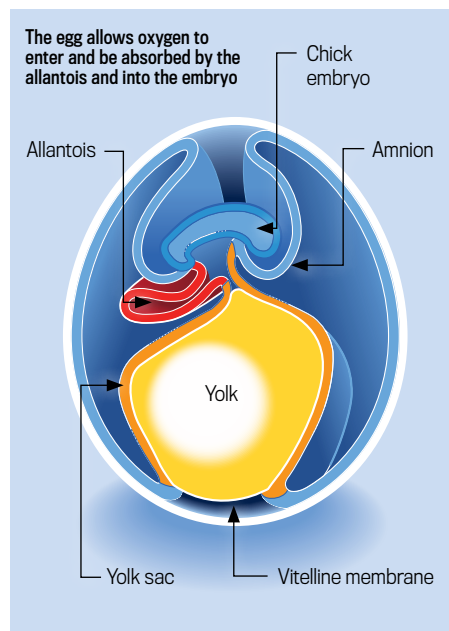
You might have more success with a timber house, though. These weigh in at around 72.5 tonnes. Commercial satellite launch costs are currently around £15,000 per kilo and can lift up to five tonnes at a time into orbit. If you built your house in sections and sent it up over 15 launches, it would cost just over £1.1 billion.

But this is the cost of launching it into orbit. Most of the fuel used in a satellite launch isn't used to gain altitude. It's for accelerating the satellite to the horizontal speed needed to achieve a stable orbit so it doesn't fall back down again. That's about 7km/s (15,600mph) for low Earth orbit. A weather balloon will lift a small payload to over 30km, which is still within the upper atmosphere but is referred to as 'near space'. With 27,000, 8.5m-diameter balloons, you could lift the house to 30km for £1.7 million. **LV**

Q JACOB SMITH, FAREHAM

How do chicks breathe when in the egg?

A ALTHOUGH A BIRD embryo has no functioning lungs, the eggshell isn't airtight, so gases can still diffuse in and out. A special membrane called the allantois forms as a sausage-shaped offshoot of the developing gut. It's covered with a fine web of blood vessels that increase the surface area in order for oxygen to diffuse into the blood and CO₂ to diffuse out. The allantois is one of the adaptations that allowed animals to move from the ocean to the land. Fish and amphibian eggs don't have an allantois, but bird and reptile eggs do. In mammals, the allantois develops even further, to form the umbilical cord. **LV**



The egg allows oxygen to enter and be absorbed by the allantois and into the embryo

Chick embryo

Amnion

Allantois

Yolk

Yolk sac

Vitelline membrane

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January

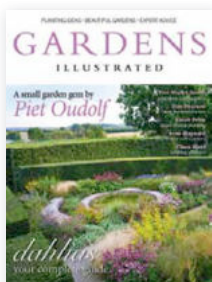


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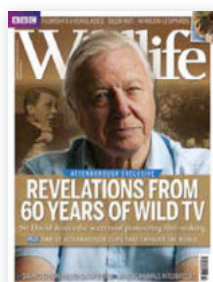
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HOW DO WE KNOW?



HOW THE CONTINENTS FORMED

BY DR CHERRY LEWIS

Once scientists discovered that the continents were once joined together, the race was on to explain how they drifted apart

E

ver since maps were made, people have noticed how the east coast of the Americas looks like it once fitted snugly into the west coast of Africa and Europe – it isn't a perfect fit, but it's good enough to make many wonder whether they had once been joined together. As early as 1596,

Dutch map-maker Abraham Ortelius considered that the Americas had been 'torn away from Europe and Africa... by earthquakes and floods'.

Over the following centuries, several others noted the remarkable correspondence between the two coastlines, but it was Antonio Snider-Pellegrini who in 1858 first reconstructed the continents as they might have looked before the split. Citing matching fossils and rock formations on opposing sides of the Atlantic to support his ideas, his reconstruction showed a single landmass as it was on the first day of Creation. Following a violent expansion of the Earth's crust, caused by the eruption of volcanic material along a north-south fissure, the

continents had attained their current positions by the sixth day of Creation.

In 1875, John Pepper used Snider-Pellegrini's idea of a single landmass to support his arguments for the formation of coal, found on many continents around the world: "The uniformity of the fossil plants of the coal measures of Europe and North America is convincing proof of the former existence of a continent... where the Atlantic now rolls its waves". If the continents had not been joined together when the coal was being deposited, how else could this phenomenon be explained? It was another 35 years before anyone asked that question again.

THE EARTH MOVES

Alfred Wegener was a German meteorologist who, in 1910, was working at Marburg University in Frankfurt. For Christmas that year his roommate was given the latest edition of a colour atlas. As the two men pored over the beautiful maps, a thought occurred to Wegener: "Does not the

east coast of South America fit the west coast of Africa as though they had been contiguous in the past?" Wegener was so inspired by this revelation that he determined to start looking for evidence to support it.

In 1912 he felt confident enough to give his first lecture on the subject, publishing *The Origin Of The Continents And Oceans* in 1915. The book detailed the extensive evidence he had collected in support of his theory, which stated that during the late Palaeozoic era (about 350 million years ago) all the continents had been grouped together in one vast supercontinent he called Pangaea. As Pangaea started to break up, the continents slowly drifted apart, eventually arriving at their current positions. Some of the most convincing evidence was the palaeontological data. Not only did the tropical flora of the coal measures noted by Pepper demarcate the equator of Pangaea, but *Glossopteris* ferns of the Permian era, which grew in a polar climate, were shown to cluster around Pangaea's South Pole. Moraines, tills and



> IN A NUTSHELL

Today, the concept that the continents sit on moving plates – and that earthquakes and tsunamis are caused by those plates shifting – is common knowledge. But while such ideas were first put forward in the 1500s, it wasn't until the 1960s that the theory of continental drift was conclusively proven.

→ other debris left behind by the retreating Permian glaciers, which were otherwise inexplicably dispersed across all continents, were explained if an icecap covered these continents at that time because they were located at the South Pole. There was also evidence from reptiles, earthworms and other organisms. The earthworm distribution seemed to be particularly significant because they can neither swim nor fly. How could they have become dispersed around the world unless the continents had once been joined together?

In both Britain and America, Wegener's ideas were received with incredulity and disbelief. To most, the continents had always been, and always would be, stationary. It was impossible to imagine them moving, so his radical ideas only attracted hostile criticism, particularly from geologists, whose favourite theories were being unceremoniously overturned.

The conventional hypothesis that explained the same rocks and fossils being found either side of the Atlantic was 'land bridges'. Adherents argued that animals had walked from one side

of the Atlantic to the other, taking with them the seeds of plants and trees, the fossils of which were also found on both sides. But where were these land bridges now? Since the flora and fauna began to diverge after the Jurassic, it was assumed that the land bridges had sunk beneath the waves during the Cretaceous era. But could such a land bridge have stretched 8,000km across the Atlantic? Most geologists believed so, for although they saw the logic of Wegener's arguments, there was one question that could not be answered. Just how did the continents move?

THE KEY EXPERIMENT

A dating method using deep-sea core samples proved that the theory of continental drift was correct



The process of potassium-argon dating, as seen here, was crucial in helping to prove theories of continental drift

A method for dating certain rocks, known as potassium-argon dating, was pioneered in the 1950s, when geologists wanted to know how frequently magnetic reversals occurred. By the early 1960s, a geomagnetic reversal timescale was developed to allow Fred Vine to correlate onshore reversals with sea floor reversals and demonstrate that

the ocean floors were youngest close to the ridge and oldest next to continents. It appeared to confirm Harry Hess's theory of seafloor spreading and continental drift.

Verification of Vine's work was provided by palaeomagnetic investigations of 650 samples from sediments in seven deep-sea cores taken from the

Antarctic. Comparing the age and geomagnetic stratigraphy of the marine sediments with the onshore lavas provided an excellent correlation, thus linking the continents and oceans. The study also confirmed that at least 11 geomagnetic reversals had occurred over the last 3.5 million years. Vine used this enhanced timescale of reversals

to predict the magnetic profile that would be expected across the central regions of mid-ocean ridges. By varying the estimated spreading rate, it was possible to obtain a very close simulation of all the observed anomalies and consequently determine the actual spreading rates at individual ridges. The theory of plate tectonics was born.

Geophysicists in particular complained that Wegener's mechanism to explain this was physically impossible. Wegener had argued that as continents were composed of less dense material than that which formed the ocean floor, they would float in the substrate, like icebergs at sea. But how could they plough through the hard rock of the ocean floors? The idea was preposterous and the arguments rumbled on for more than a decade before anyone came up with a plausible solution.

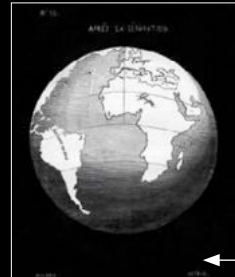
The British geologist, Arthur Holmes, was one of the few who favoured continental drift. Having pioneered the application of radioactive decay to dating rocks, Holmes worked throughout the 1920s on trying to understand the Earth's interior, coming to a realisation that the heat generated by the decay of radioactive elements within the Earth was what kept the interior hot. In December 1927 he wrote a groundbreaking paper, postulating that differential heating of the Earth's interior, generated by the decay of radioactive elements within it, caused convection in the substratum beneath the crust. Although the substratum appeared solid, Holmes believed that over vast periods of time it behaved like a very thick, hot liquid; as hot material reached the top of a convecting cell beneath a continent it would travel horizontally, producing a force that was sufficient to slowly drag the continents apart, allowing the substratum to rise into the gap and form new ocean floor. This convection, Holmes claimed, was the mechanism that drove continents around the globe. But like Wegener, Holmes was ahead of his time. Amid much opposition, their theories languished for another 35 years.

UNDERWATER WORLD

In the 1950s, mapping of the ocean floors by American geologists revealed the Atlantic to have extensive flat plains interrupted by a vast mountain range of valleys and ridges, the central Mid-Atlantic Ridge being the epicentre of many earthquakes. Subsequently this was found to be part of a 80,000km system of mid-ocean ridges that encircled the world. At the same time, other groups collecting magnetic data from the ocean floors found

CAST OF CHARACTERS

The scientists whose efforts forged a bright future for geology



Antonio Snider-Pellegrini (1802-1885) was an Italian-American geographer who was the first to illustrate the continents as a single landmass, citing fossils and matching rock formations on opposing sides of the Atlantic to support his ideas.



Alfred Wegener (1880-1930) was the German meteorologist who first proposed the theory of continental drift. He compiled a database to support his theory that the continents were slowly drifting around the Earth and had once been joined in a single landmass. He died on a polar expedition and did not live to see his theory revolutionise the Earth sciences.



Arthur Holmes (1890-1965) proposed convection currents in the mantle as a mechanism for driving continents around the globe. But like Wegener, the British physicist's ideas were ignored for decades.



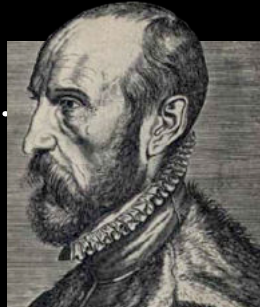
Harry Hess (1906-1969) was a geologist at Princeton University who suggested that the Earth's crust moved laterally away from volcanically active mid-ocean ridges. His theory of seafloor spreading made him one of the 'founding fathers' of modern plate tectonics.



Fred Vine (b. 1939) proposed, along with Drummond Matthews (pictured to the right of Vine), that magnetic stripes either side of mid-ocean ridges recorded the orientation of the Earth's magnetic field. He went on to provide evidence that verified continental drift.

TIMELINE

Continents move over thousands of years – and it took us nearly 400 to figure out how the process works



Abraham Ortelius suggests in print, having studied the first modern maps of the whole world, that the Americas had at some point in history been "torn away from Europe and Africa".

1596

1858

Antonio Snider-Pellegrini depicts the continents as a single landmass on the first day of Creation, in a book entitled *The Creation And Its Mysteries Unveiled*.

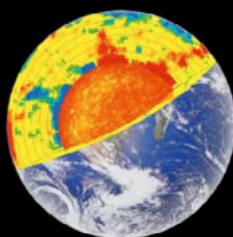


Alfred Wegener proposes his theory of continental drift in which a single landmass, Pangaea, existed during the Carboniferous era. When Pangaea broke up, the fragments drifted slowly to their present positions.

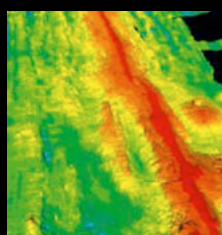
1912

1927

Arthur Holmes suggests convection currents in the mantle as the mechanism for driving continents around the globe. Lack of a mechanism was hitherto a major obstacle preventing the acceptance of continental drift.



1950



Harry Hess proposes 'seafloor spreading', whereby convection within the mantle brings molten material to the surface at mid-ocean ridges, slowly pushing the continents apart.

1962

Mapping the ocean floor reveals vast mid-oceanic ridges that circumnavigate the globe, and a pattern of magnetic stripes that mirror each other either side of the ridges.

➔ a surprise beneath the Pacific: a pattern of linear magnetic stripes on the ocean floor that mirrored each other either side of the mid-ocean ridge with almost perfect symmetry.

Since the early 20th century it had been recognised that when rocks such as basalt (lava) cooled from their molten state, the magnetic particles within them become 'fossilised', pointing in the direction of the Earth's magnetic field. While it was noted that some rocks appeared to be magnetised in the opposite direction, it was not until the '50s that people realised this was caused by the polarity of the Earth's magnetic field periodically flipping over, such that the South Pole became the magnetic pole. By dating thick onshore lava flows, a time scale of these magnetic 'reversals' was gradually built up. Nevertheless, it was some years before the significance of the magnetic stripes found on the ocean floors was understood.

In 1962, Harry Hess, then Head of Geology at Princeton University in the United States, put forward a startling proposal. Seafloor spreading, as Hess's theory became known, predicted that as 'rising limbs of mantle-convection cells' welled up from the depths beneath the mid-ocean ridges, the new material pushed the previous flow apart so that half would move to either side of the ridge, slightly widening the ocean each time. Eventually the original flow would end up thousands of kilometres away from the ridge. The two continents, once part of the same landmass, would be thousands of kilometres distant. Furthermore, instead of continents ploughing through oceanic crust as Wegener had proposed, Hess had them riding on a conveyor belt of convecting mantle. He made only passing reference to Holmes's work 35 years earlier.

EARTH'S BARCODE

The significance of the ocean floor's magnetic stripes then dawned on two British geophysicists, Fred Vine and his PhD supervisor at Cambridge, Drummond Matthews. In 1963 they proposed that if spreading of the ocean floor occurred as Hess suggested, the stripes must represent the periodic 'flipping' of the Earth's magnetic field, fossilised in basalts as they oozed out from the mid-ocean ridge. Over millions of years, the orientation of the Earth's magnetic field had been

NEED TO KNOW

Your glossary of terms related to geology and plate tectonics

1 Basalt

A type of rock erupted from volcanoes and at mid-ocean ridges.

2 Crust

The oceanic crust is about 4.8km thick and is nowhere older than 200 million years, while continental crust can reach 64km thick and be anything up to four billion years old.

3 Lithosphere

The crust plus the solid part of the upper mantle – about 80km deep.

4 Magnetic reversals

The Earth's magnetic field has frequently been reversed over geological time. This is recorded in certain mineral-containing rocks, which align with the prevailing magnetic field.

5 Mantle

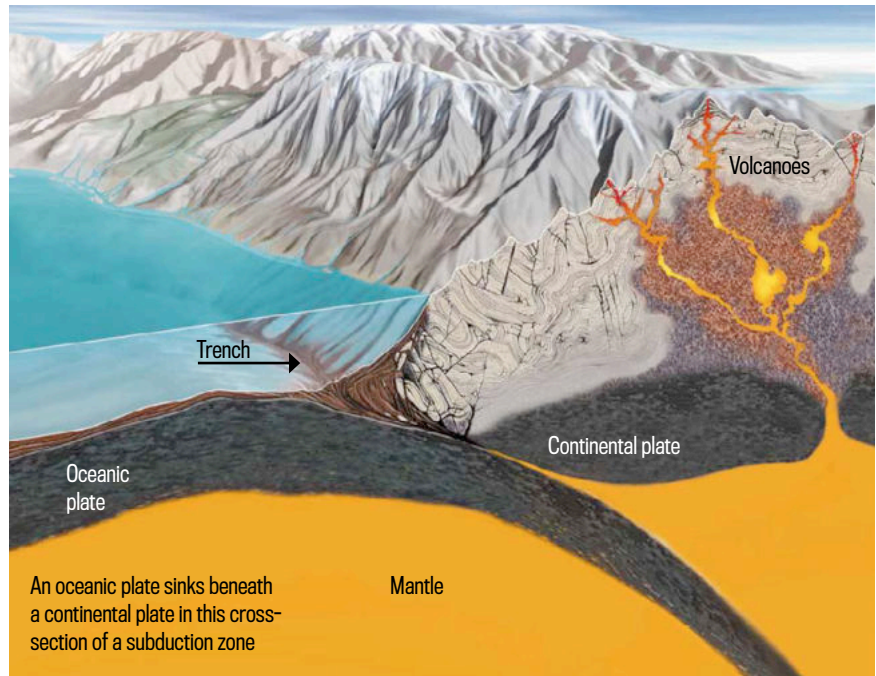
The mantle is everything that lies beneath the Earth's crust, and above the liquid part of the core.

6 Mid-ocean ridges

An underwater mountain range, formed by seafloor spreading, that circles the Earth like the seams of a baseball.

recorded like a barcode. Canadian Lawrence Morley proposed a similar explanation in January that year, but his work was rejected by scientific journals as being too controversial.

In 1965, a new magnetic survey of the Juan de Fuca Ridge in the northeastern Pacific was made. Vine correlated the data with dated reversals from onshore lava flows and calculated the ages of the reversals on the sea floor. It was immediately evident that the youngest rocks were nearest to the ridge, while the oldest were furthest away and adjacent to the continent. The following year, samples from deep sea cores from the Pacific showed that the timing and pattern of magnetic reversals in the core samples



matched those determined from lava flows on land. This verified Vine's work and the theory of continental drift at long last became indisputable.

TECTONICS TODAY

Today's lithosphere is divided into eight large plates and many smaller ones. Their average rate of movement is about 4cm a year – about the rate your fingernails grow. What's still not entirely clear, however, is why some plates move faster than others.

The process generally starts with heating at the base of the continental crust, which causes it to become more plastic and less dense. Because less dense objects rise in relation to denser objects, the heated area becomes a broad dome. As the crust bows upward, fractures occur that gradually grow into rifts which start to break up the continent. Eventually basaltic material wells up between the continental fragments, pushing them further and further apart until an ocean such as the Atlantic forms.

Ultimately, old oceans like the Pacific begin to close. The oceanic plate descends beneath the continents, forming a vast trench, or subduction zone, up to 10km deep. As the enormous slabs push their way back into the mantle, deep earthquakes can often be felt at the surface. Sediments, formerly on the ocean floor, begin to heat up, melting and rising through the crust to

form mountain chains of volcanoes along the edge of the continent. The 'ring of fire' around the Pacific, for example, is caused by oceanic crust being subducted beneath the continents. When continents collide with each other, as when India crashed into Asia about 50 million years ago, vast mountain chains like the Himalayas rise up. In other places like the San Andreas Fault, where continents are grinding past each other, more shallow earthquakes can cause terrible damage at the surface.

By the end of the 1960s, a revolution had occurred in geology, comparable to that caused by Darwin a hundred years earlier in biology, when he proposed his theory of evolution. Today, the great unifying theory of plate tectonics, as continental drift is now called, explains just about every geological feature you care to imagine. ■

Dr Cherry Lewis is a geologist and the author of *The Dating Game: One Man's Search For The Age Of The Earth*

Find out more

Coming soon: *The Story Of The Continents*, with Prof Iain Stewart

Listen to a 2008 episode of *In Our Time* on plate tectonics from 2008, with Melvyn Bragg and guests <http://bbc.in/LnGRAN>

FOCUS

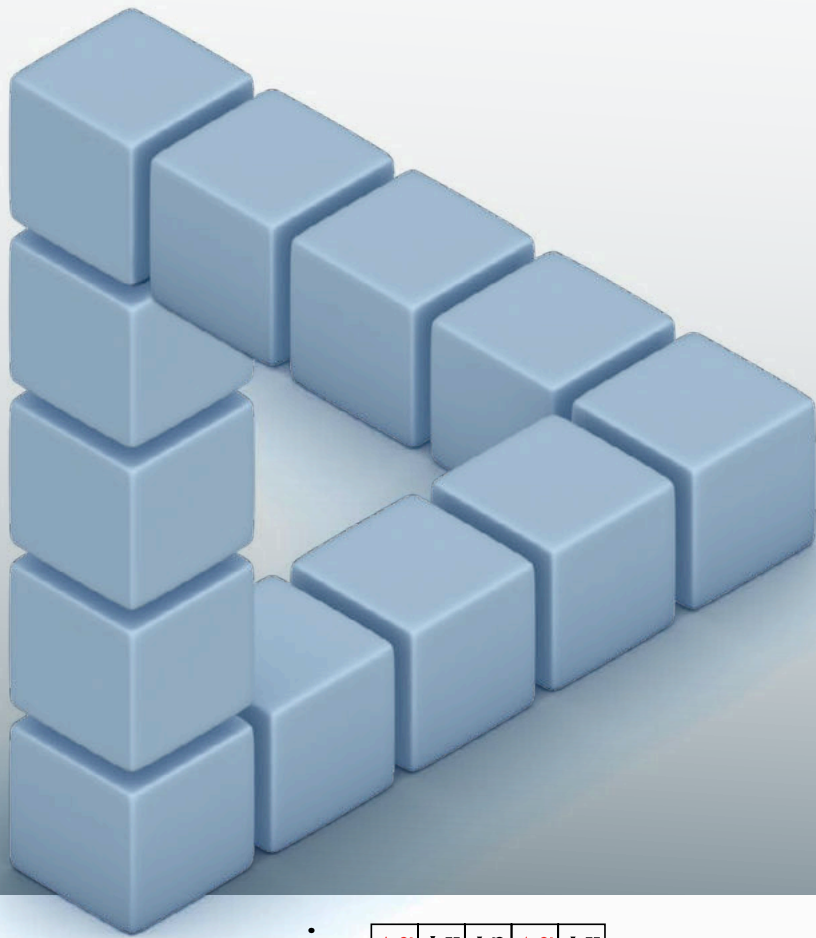
SCIENCE AND TECHNOLOGY

MARCH ISSUE

THE TRUE NATURE OF REALITY

WHY IT'S NOT WHAT YOU THINK

ON SALE
7 FEBRUARY



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♠ 10	♥ K	♣ K	♠ 10	♥ K	♣ K
♠ 7	♥ 7	♣ J	♠ 3	♥ J	♣ J
♠ 2	♥ 3	♣ 6	♠ A	♥ 4	♣ 4
♠ 6	♥ 5	♣ 6	♠ 6	♥ 6	♣ 5
♠ 8	♥ J	♣ 9	♠ 10	♥ 8	♣ 8

MINDGAMES PUZZLE
SOLUTION
Stop cheating! Don't look at this until you've attempted the puzzle on p111.

TO DO LIST

PLAN YOUR MONTH AHEAD WITH OUR EXPERT GUIDE

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-  LISTEN
-  TOUCH
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PICK OF THE MONTH



The Genius Of Invention

Miodownik, Newland and Mosley: the trio of TV scientists behind *The Genius Of Invention*

➔ FOR A LONG time, programmes about the transformation of our world through technology have been the poor relations of science television, seen as old-fashioned and foggish, and presented by hairy-faced eccentrics. At last, somebody has noticed that millions of people enjoy these shows, and that even audiences born long after mills and mines closed down are hungry to know more about Britain's industrial history.

This series brings together history, engineering and science, with three presenters exploring four inventions that shaped our world. In each episode, materials scientist Prof Mark Miodownik, industrial archaeologist Dr Cassie Newland and Dr Michael Mosley will tell the story from an appropriate place.

The first programme will report from Drax power station in Yorkshire on how the development of power from steam to electricity has changed our lives. As we'll learn, even the most modern generating stations rely on the same basic inventions – the electrical dynamo and, in most

cases, steam to push it round. So every time you turn a light on, think of the enduring steam engine.

The other programmes will look at transport, telecoms and the moving image. We'll move from steam trains to jet engines, from the telegraph to mobile telephones, and from early photography to HDTV. And since the history of invention is tied in with British institutions like Rolls-Royce and the GPO (now BT), we'll see something of them as well.

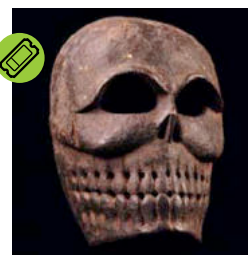
The team of enthusiastic, engaging presenters and their breadth of knowledge combine to make this series entertaining as well as informative. It may even lead to a revival of interest in British engineering. In fact, it's a wonder nobody thought of doing it before. After all, without *Yesterday's World*, we'd never have had *Tomorrow's World*.

TIMANDRA HARKNESS



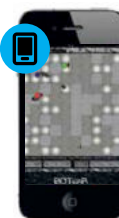
The Genius Of Invention airs on BBC Two in February – see radiotimes.com for details

DON'T MISS!



Death: A Self-Portrait

A new exhibition looking at everything from death in films to the psychology of bereavement. **p98**



BOTwaR

Learn JavaScript...

by programming a robot to do battle! Seriously, what's not to like about this new iPhone and iPad app? **p102**



The Cosmic Tourist

Visit 100 of the Universe's most exotic destinations in this final work by the late Sir Patrick Moore. **p104**



VISIT

EVENTS & EXHIBITIONS

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23 JANUARY

Bright Club

The Black Swan Venue & Bar, 7.30pm-10pm, £3, j.mp/brightclubnewcastle



MIXING SCIENCE, MUSIC and comedy, Bright Club is for curious minds on the hunt for an evening's entertainment. Comedian Helen Keen (pictured) hosts the evening along with local scientists and students to create a variety night like no other. Book online, then pay £3 on the door (and do get there before it starts, as any unclaimed tickets will be resold).

26 JANUARY

Monsters, Microbiology And Mathematics: Zombie Survival Training

MOSI, Manchester, free, www.mosi.org.uk



IF A PANDEMIC was to sweep the globe, how would we react? In this drop-in session, discover the methods created to cope with outbreaks of infectious diseases. Decide your response, then watch a computer simulation to see if your strategy works. You never know when you might need to deal with an impending apocalypse.

28 JANUARY

What Can We Learn From Our Genes?

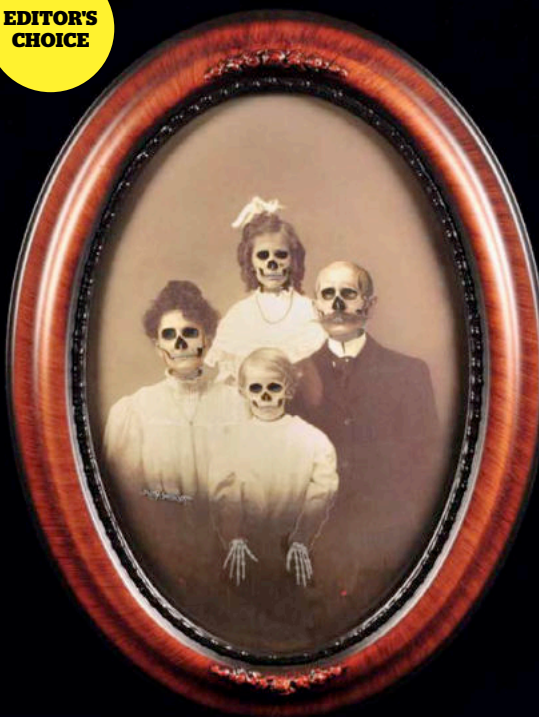
Royal Society, London, 6.30pm-8pm, free, royalsociety.org



A DECADE AGO, politicians encouraged scientists to hype the immediacy of medical breakthroughs resulting from sequencing the human genome. But 10 years on, how much do we really know about our genes? And has that knowledge actually helped us develop new medicines and therapies? Find out at this Café Scientifique event led by Dr Ewan Birney, Associate Director of the European Bioinformatics Institute.

JHENI OSMAN is a science writer and the author of *100 Ideas That Changed The World* (BBC Books, £9.99)

EDITOR'S CHOICE



Marcos Raya's *Family Portrait*, 2005, one of the artworks in the Wellcome Collection's exhibition on death - morbid but undeniably fascinating

FROM 26 DEC

Death: A Self-Portrait

Wellcome Collection, London, ticket prices vary, www.wellcomecollection.org

IF YOU'VE EVER watched the movie *Highlander* you'll realise that immortality isn't necessarily a good thing. Nevertheless, scientists like Aubrey de Grey and inventors like Ray Kurzweil are hunting for ways to cheat death. Even Kazakhstan's president tasked scientists with finding an elixir to prolong his life. The result, after two years of research, was a liquid called 'nar' - a probiotic yoghurt not altogether dissimilar to Yakult.

In this series of exhibitions, talks and films, the Wellcome Collection is investigating what scientists are so keen to avoid: death. On 16 January, join a funeral director to find out exactly what they do, and discover the psychology involved in helping loved ones deal with their loss. On 19

January, there is a day-long film festival screening artists' short movies about death. On 23 January, science writer Marek Kohn explores death with the help of a morbid mystery object. Then on 1-2 February, there's an evening of performance followed by a full day of talks and discussion exploring the idea of a 'good death', looking at how this concept has changed through history, and how it relates to modern medicine. And until 28 February, there's an exhibition of artworks that investigate how death is interpreted, and our complex and contradictory attitudes towards it.

Yes, death is grim, sombre and depressing, but it's an intriguing topic nonetheless - and one that, sooner or later, will affect us all.

30 JAN-3 FEB

Zombie Lab

Science Museum, London, free, sciencemuseum.org.uk



ARTIFICIAL INTELLIGENCE, ANIMAL rights and the treatment of patients with brain damage are currently hot topics in the scientific field of consciousness. This five-day festival focuses on the science of consciousness in its many forms, investigating how the field will develop in the future. And because zombies are hot right now, the whole week is themed around these mindless movie horrors.

5 FEBRUARY

Astroseismology: Using The Natural Music Of The Stars

The Jekyll & Hyde, Steelhouse Lane, Birmingham, 7pm, free, www.thinktank.ac/cafe_sci



STARS MAKE MUSIC – and we're not just talking pop stars! At this Café Scientifique event, join Prof Bill Chaplin from the University of Birmingham to find out how stars make sounds and how scientists interpret them to reveal their inner workings. Plus, discover how this helps us find planets beyond the Solar System.

FROM 7 FEB

Ice Age Art: Arrival Of The Modern Mind

British Museum, London, £10, www.britishmuseum.org



BY LOOKING BACK at early artworks, we can discover when the human mind first began to store, transform and communicate ideas. This exhibition of the earliest European sculpture, ceramics and drawings, from 10,000-40,000 years ago, shows how their creators' brains had developed sufficiently to express themselves through art and music.

FROM 8 FEB

Extinction: Not The End Of The World?

Natural History Museum, London, £8 adults/ £4 children and concessions/£21 family, www.nhm.ac.uk



EXTINCTION IS CRUCIAL to evolution. Using real specimens and interactive installations, this exhibition goes back beyond the dodo to show how the end of some species has allowed others to blossom, and also looks at current ailing species, asking if conservation can truly save them.

SPEAKER OF THE MONTH

21 JANUARY


Maria Konnikova

Watershed, Bristol, 7pm-8pm, £7, www.ideasfestival.co.uk



Who is she?

Maria writes is a science writer who explores the connections between literature and psychology. Born in Moscow, Maria grew up in the US and graduated from Harvard University. She holds an MPhil in psychology and an MA in political science. Her first book is *Mastermind: How To Think Like Sherlock Holmes* (reviewed on p105).

What's she talking about?

How you can have an active mental disposition, be perpetually mindful and organise your thoughts – which in Holmes's case is akin to ordering the "brain attic". Maria also looks at logic, deduction, creativity and imagination, using cutting-edge neuroscience and psychology to explain and understand Holmes's methods.

UNTIL 24 FEB

Reconstructing Lives

National War Museum, Edinburgh Castle, free with Castle admission, www.nms.ac.uk/reconstructinglives


LAST CHANCE TO SEE


WITH THE CONFLICT in Afghanistan resulting in military personnel and civilians sustaining terrible injuries, this exhibition is a timely reminder of what it is like to lose an arm or leg in war. With stories from amputees, the exhibition showcases the technology which has helped to rebuild lives. On display are all sorts of prosthetics, including wooden peg legs from Roman times, 16th-Century armour-like iron hands, and the cutting-edge i-limb hand developed by Touch Bionics.



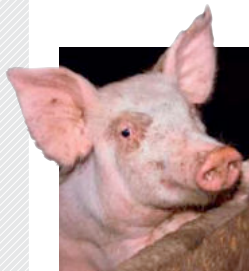
WATCH

TV, DVD, BLU-RAY & ONLINE
WITH TIMANDRA HARKNESS

TBC

Nature Shock

Channel Five, TBC

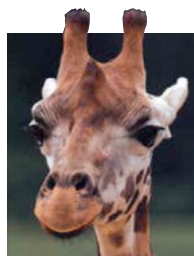


THE SERIES THAT does for wildlife what *Geordie Shore* did for Newcastle returns with more bizarre tales from the animal kingdom. How often do you get to witness a giraffe killing spree in Tanzania? Other improbable mysteries include Indian elephant stabbings and combustible North American pigg. Meanwhile, in South Africa the sharks are forming gangs... possibly with the aim of landing themselves parts in a new Durban-based production of *West Side Story*. Or possibly not.

FROM 2 JAN

Africa

BBC One, starts 2 January, 9pm



THIS NEW SERIES narrated by Britain's hardest-working 86-year-old, Sir David Attenborough, explores the varied terrains and abundant wildlife of Africa - from the plains of the Serengeti to the peaks of the Ruwenzori mountains, and from mighty lions and elephants to tiny lizards. Look out in particular for the four-foot-tall shoebill, a odd-looking, stork-like bird that gives birth to two offspring... one of which will always kill the other before they reach adulthood. And you thought having the kids bickering in the back seat was bad...

JANUARY

Kangaroo Dundee

BBC Two, January, date/time TBC



THIS TWO-PART special tells the unlikely story of an Australian who becomes mother to orphaned kangaroo babies. Tough guy Chris 'Brolga' Barns (pictured) may look more Clint Eastwood than Mary Poppins but, inspired by kids' TV series *Skippy*, he turned his back on his city upbringing to create a kangaroo sanctuary in the remote bush. Rescuing a marsupial baby is no easy job - small as a jellybean, naked and blind, they can't survive outside their mother's pouch - but don't worry, Brolga won't let them perish! Awww.

TIMANDRA HARKNESS is a BBC Radio 4 presenter and stand-up comic. Her live shows include 'Humans Vs Nature: Engineering FTW'

EDITOR'S CHOICE



David Attenborough goes on the hunt for unlikely pairings in nature

FROM 29 JAN

David Attenborough's Natural Curiosities

Eden, starts 29 January, 8pm



WHAT LINKS THE spirals of a snail's shell and a narwhal's horn? Or a giraffe's neck and a chameleon's tongue? For a start, these unlikely pairings and more appear in David Attenborough's new series, inspired by a 17th century natural history book he saw as a child. Because after 60 years in broadcasting, the biggest name in wildlife television is taking a new approach for his latest series.

Instead of a sweeping panorama of the animal kingdom, each episode will focus on just two creatures, and one extraordinary thing that links them. "This extra dimension to animals sets you thinking about why they are the way they are," says Sir David, "which is something that I don't think we've really done on television before."

The giraffe and the chameleon, for example, have both evolved an unusually long body part. The chameleon's tongue is not as obvious as the giraffe's neck, but can stretch to twice the reptile's body length and move five times faster than a fighter jet. Another episode looks at reproductive quirks: the midwife toad is an oddity in having a father as primary caregiver to the fertilised eggs, but not as odd as the duck-billed platypus, one of the few creatures to both lay eggs and suckle its young.

Filmed entirely in the UK, the series also proves that you don't have to travel the world to discover the science behind the zebra's stripes or the elephant's wrinkles. Or why a left-handed snail cannot mate with a right-handed snail.

FROM 14 JAN

Britain In Motion

Blighty, starts 14 January, 10pm



FROM TELFORD TO Royce, with Brunel along the way, the UK once led the world in transport technology. The canal boat, motorcycle and aeroplane got us moving faster and further than ever before, while the hovercraft and the steam locomotive were invented right here. This series delves into the history of British transport engineering and shows how its legacy survives in today's industries.

14 JAN

Why The Industrial Revolution Happened Here

BBC Two, 14 January, 9pm



THREE HUNDRED YEARS ago, just a few technological innovations transformed Britain from an agricultural society into the richest, most powerful nation on Earth. In this documentary, Professor Jeremy Black tries to answer the two key questions of history – why then, and why here? The answers involve huge coal reserves, growing political liberalism and the burgeoning empire. Contrary to the Olympics opening ceremony, massive top hats may *not* have played a key role.

FROM 11 FEB

Air Crash Investigation

National Geographic, starts 11 February, 9pm



Find out how the causes of plane crashes are determined by investigation teams

➔ **NEIGHBOURS JETTING OFF** for some winter sun? Invite them round the night before to watch one of these horrifying stories of what can happen when aviation goes bad. Mechanical catastrophe, engine failure on take-off or even a pilot whose mind is disturbed can result in dozens of casualties. And when the crash happens over jungle, sea or mountains, the investigators may have a hard time finding the causes to prevent similar accidents. Flying's still the safest way to travel, but no need to tell your neighbours that...

DVD & BLU-RAY



The Substance: Albert Hoffman's LSD

DVD, Soda Pictures, £12.99

Since chemist Albert Hoffman discovered LSD in 1943, it has played many roles: weapon, recreational drug and psychiatric medicine. This film tells the fascinating story of lysergic acid diethylamide and its bizarre effects on the human brain, and includes an interview with the 100-year-old Hoffman himself.



Doctor Who: The Legacy Collection

DVD, BBC, £13.99

Think you've seen every *Doctor Who* ever? You may have missed *Shada*, a six-part adventure that was never completed because of a 1979 strike, though fragments of it appeared in *The Five Doctors*. Here, it's reassembled with Tom Baker narrating missing sections of the story. Also included is BBC documentary *More Than 30 Years In The Tardis*.



Sci Fi Science

DVD, Discovery, £17.99

Physicist Michio Kaku explores the science of science fiction. He has his eye on gadgets from sci-fi films and books, including lightsabers, force fields and warp drives, and asks top researchers whether stuff like invisibility, teleportation and superpowers will ever be possible.

FROM 16 JAN

Fat & Back

Discovery Home & Health, starts 16 January, 9pm



NOTCHED UP A few kilos over Christmas? Finding it hard to stick to that New Year's Resolution diet? You'll enjoy this: personal trainer PJ takes on the challenge of gaining 40kg (6 stones) and then losing it again, all within a year. He's slimming alongside Michelle, who's always struggled with her weight. And guess what? It's not as easy as he expected. Have the popcorn handy.

FROM 30 JAN

Mankind: The Story Of All Of Us

History, starts 30 January, 10pm



STEPHEN FRY'S SERIES returns with the rise of one man whose name is still synonymous with terror, a man in whose power was the gift of wealth, fame – or an agonising death. No, not Simon Cowell but Mongolian conqueror Genghis Khan. Drawing on geography, science and natural history, the series examines the great civilisations that have shaped our world.



LISTEN

BBC RADIO PROGRAMMES

WITH TIMANDRA HARKNESS

JANUARY

Real Just So Stories

BBC Radio 4, from January

ANOTHER SERIES OF programmes revisiting Rudyard Kipling's fictional explanations of natural phenomena, this time using science. In one programme, 'The Cat Who Walked By Himself' is shown to be exhibiting typical feline male behaviour. Presenter Viv Parry also finds out how the leopard got his spots, which turns out to involve some surprising physics and chemistry as well as biology.

JANUARY

What If?

BBC World Service, from January

WHAT IF? IS an interactive season that seeks to involve the BBC's world audience in imagining the future. Shows include a *Click* live special on humans and robots, inviting the Radio Theatre audience to play games with robots. Online content will examine smart cities of the future, and competitions will invite everyone to create their own visions of the world of tomorrow. The season continues till March, so check back here for more.

21 JAN

Discovery: Quantum Biology And The Sense Of Smell

BBC World Service, 21 January, various time

WE'RE OFTEN TOLD things in the real world don't behave as they do in the weird world of

quantum mechanics. Which does make life simpler, on the whole. But we're starting to discover that quantum effects do in fact play an important role in biology, from navigation to our sense of smell.

28 JAN

Discovery: The New Genetics

BBC World Service, 28 January, various times

TEN YEARS AGO, we thought we had the human genome cracked. But then things got more complicated. First, it emerged that turning genes on and off is as important as which ones you have. Now, as Adam Rutherford finds out, even sections of our DNA that we thought were just junk might be something more.



Adam Rutherford investigates genetics

13 FEB

World Radio Day

BBC World Service, 13 February

MARCONI INVENTED RADIO 25 years before broadcasts began in the UK. In this documentary, historian Dominic Sandbrook reveals why it took so long before the BBC transmitted its first words in 1922, and how it then became a public service broadcasting corporation pursuing information, education and entertainment.



TOUCH

SMARTPHONE & TABLET APPS

WITH CHRISTOPHER PHIN



Mobento

Android, free

THERE ARE TERRIFIC repositories of knowledge in videos all over the internet, but it can be hard to find them. Mobento aims to solve this by bringing together videos from TED, Khan Academy and others, and transcribing them to help you search. You can browse subjects such as climate change, physics and astrobiology, and learn about the water canary that tests for clean water. There's also cutting-edge neuroscience imaging to explore, as well as introductions to evolution. You can also download videos to watch offline later – on the Tube, for instance.



123D Design

Mac OS, iOS, Windows; Autodesk, free plus printing costs

THE COOL THING about 123D Design isn't so much that you can build simple models in 3D on your iPad, but that, once you have wrestled a virtual model into existence, you can upload it to Autodesk and pay them to print it in 3D and then send it to you. The controls can be a little fiddly until you're used to them, and it lacks the ability to draw a flat shape and then extrude a 3D shape (like pushing Plasticine through a hole) but even so, we could get a bit obsessed...



BOTwaR

iPhone, iPod touch, iPad; David Swift, £1.49

THIS ONE IS hugely geeky, and it looks pretty ropey, but we're not even sorry. At its heart, BOTwaR is a game in which robots fight each other in an arena, according to basic rules they're programmed with. The twist is that it's you that does the programming – in popular web scripting language JavaScript, no less – and then you just set them off to fight each other with no further interaction. It's not for everyone, but it's a fun idea, JavaScript is a useful skill to learn, and it's astonishing how addictive tweaking your script can become once you get into it!

CHRISTOPHER PHIN is the editor of *TAP!* magazine



PLAY

CONSOLE & COMPUTER GAMES

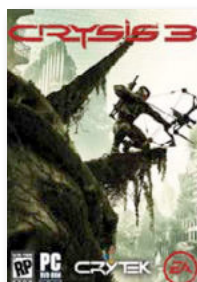
WITH NEON KELLY



Aliens: Colonial Marines

PC, Xbox 360, PS3, Wii U; Sega; £39.99

THE ALIEN FRANCHISE has a long-standing romance with video games, but *Colonial Marines* is arguably the first effort to take the relationship to obsessive levels. In this first-person shooter we revisit the highlights of James Cameron's iconic blockbuster, via a quasi-sequel plot that lets you explore the key locations. It's a bit like an interactive museum exhibit, one where the artefacts scuttle about trying to kill you. If it's all proving a bit much, up to three friends can join the fray.



Crysis 3

PC, Xbox, PS3; EA; £39.99

THERE WAS A time when the *Crysis* name was synonymous with graphical perfection, the pinnacle of PC eye candy. The series' stock has diminished since then but it's still no slouch, and *Crysis 3* is a worthy choice for gamers who like their shooters to be flashy as well as functional. This third instalment finds you battling aliens in the overgrown ruins of New York City – the literal embodiment of an urban jungle. It's also got a bow and arrow, which appears to be the must-have weapon for 2013.

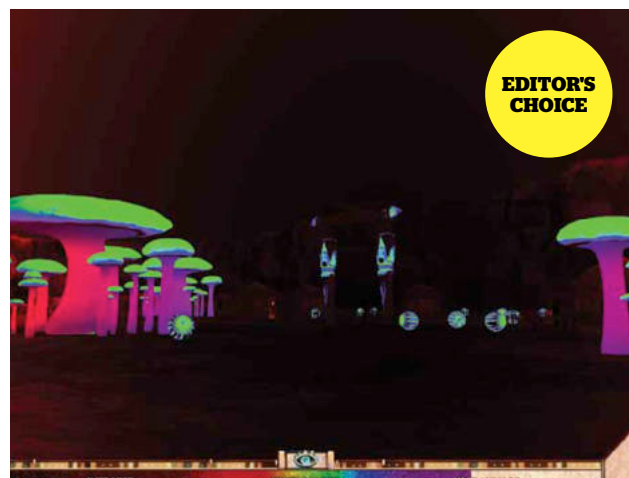


Metal Gear Rising: Revengeance

Xbox, PS3; Konami; £39.99

THE AWKWARDLY-NAMED *Revengeance* threatened to be the problem child of the *Metal Gear* series. It stars the androgynous Raiden in place of usual hero Snake, and had to switch studio midway through development – something that usually spells trouble. Luckily, the series' new developer Platinum Games is the current grand master of the action genre. The end result favours sword-based slashing in place of the usual stealth, allowing you to slice and dice everything in sight.

NEON KELLY IS DEPUTY EDITOR AT VIDEOGAMER.COM



EDITOR'S CHOICE

Trust the Massachusetts Institute of Technology to make a game about the physical properties of photons travelling at different speeds...

A Slower Speed Of Light

Windows, Mac; MIT Game Lab; Free



➔ AT ITS CORE, *A Slower Speed Of Light* offers one of the oldest setups in gaming. You run around an arena-like playground, attempting to gather 100 collectable spheres. But here's the catch: with every successful pick-up, the game incrementally decreases the simulated speed of light.

If you're a physics bod you can probably guess what happens next, but everyone else is in for a surprise. Initially your task seems to be laughably easy, but the better you fare the more distorted your perceptions become. The game realistically depicts principles like Lorentz transformation, time dilation, and the Doppler effect, which in layman's terms means that the graphics swiftly hitch a ride on the Wackjob Express.

The colours in your surrounding begin to shift and

glow and eventually the hue and tone of the world depends on the direction in which you face – I'm reliably informed that this is the Searchlight Effect. Objects begin to violently warp as you enter their vicinity, and there's a watershed moment the first time you catch sight of a strange, conical figure, and realise that you're watching your past self.

A Slower Speed Of Light is the work of MIT's Game Lab. As you might expect, it's less successful as a game, in the purest sense, than as an exercise in exploring physics. All the same, it's a lot of fun – particularly on the last stretch of your collect-a-thon quest. By then you'll find it near impossible to navigate your environment with any degree of finesse, sliding around a kaleidoscopic wonderland. If you've ever wondered what it was like to be a rock 'n' roll roadie in the '60s, this is probably a fairly accurate depiction.

In addition to releasing the game for free, the MIT Game Lab plans to publish its engine as an open-source package later this year. In theory, that could lead to a whole new crop of distorted-light games. Is *Mario's Doppler Freak-out* just around the corner? Here's hoping.



READ

THE LATEST SCIENCE BOOKS REVIEWED

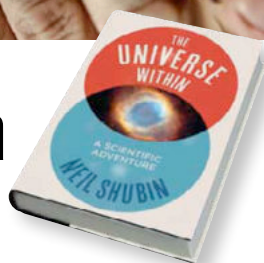
H Hardback **P** Paperback



Neil Shubin with a fossilised bone of *Tiktaalik roseae*, a fish that is thought to mark a transition between aquatic and land animals

The Universe Within A Scientific Adventure

Neil Shubin
Allen Lane **H** £20



A PALAEOLOGIST BY training, Neil Shubin presents a panoramic view of our planet over the past few billion years, including how life as we know it came to be. Grounded in his own field work, with vignettes of hunting fossils in far-flung parts of the world, it reveals how our bodies have come to be due to cosmic events in the distant past. While this sounds somewhat esoteric, it comes across very clearly, with each chapter describing a different epoch and what its consequences are for us. The constant harping on about how we carry the signatures of these past episodes within us is somewhat artificial and irritating, but the arguments to defend his position are convincing.

Since the coverage of this book is so sweeping over the aeons, it is inevitable that some of the treatment ends up being superficial, even occasionally slightly inaccurate when Shubin strays too far from his own academic roots. It is

deliberately written as a romping, extensive story – the ‘adventure’ of the title – full of photos of the scientists and explorers who have contributed to the unfolding of our narrative. I found these potted histories of individuals fascinating. Many of them were not names I knew, and their place in the development of scientific ideas was unfamiliar to me, and all the more interesting for that.

The book carries the reader along on a wave of enthusiasm for the subject, but leaves rather less room for reflection. I enjoyed it as a brief summary of many complicated and interwoven facets of our deep history, but I could not recommend it as a book that would serve as a useful reference guide.



ATHENE DONALD is a Professor of Experimental Physics at the University of Cambridge

MEET THE AUTHOR



Neil Shubin

Why did you write this book?

When I describe to people the vastness of space and they consider the enormity of galaxies, for instance, they look at me and say: “Is it your job description to make us feel tiny and puny?”. I guess this book is a response to that – instead of feeling tiny and insignificant, there’s this history as big as the Universe inside each one of us. To me, there’s almost a sense of aesthetic beauty to the connections we see between us and the non-living world.

Could you give an example of how the human body is linked to the history of the Universe?

One of the most fundamental biological properties that lies inside us is the way our cells work on deep molecular clocks, and so much of our health and wellbeing depends on them. These clocks aren’t random – they’re tuned to the basic rotation and properties of the Earth, which began in events over 4 billion years ago when we had the formation of the Earth-Moon system. So the clocks reveal our shared history with the planet and the Solar System.

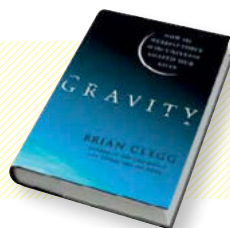
Which part of the book was the most challenging to write?

Each of these stories could have been a book in itself, so for me the challenge was distilling the essence of each story into something that’s meaningful but that’s also scientifically correct. I had to work and rework it a fair amount of times because I didn’t want the book to be 1,500 pages long – I wanted it to be digestible and readable.



MORE ON THE PODCAST

Listen to the full interview with Neil Shubin on the podcast at sciencefocus.com/podcasts



Gravity

Brian Clegg

Duckworth £14.99

BRIAN CLEGG'S BOOKS are always easy to read and simple to understand. But, unfortunately, significant parts of his latest clear and accessible book on the force of gravity are just plain wrong.

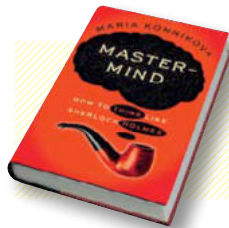
Clegg makes the classic howler of referring to 'annual variations from spring tide to neap tide', confusing the season of spring with tides that 'spring up' very high at both New and Full Moon. He also tells us that if the Solar System lasted long enough for lunar tides to slow the Earth's spin until it always had the same face towards the Moon, the Earth would be rotating 'only once a year'. It should, of course, be once a month!

There are also sins of omission. We are told that when a photon hits a mirror it is absorbed by an atom and re-emitted 'to fly off in a different direction'. This is true, but it is also what happens when a photon hits a non-mirrored surface. There's more to the story, but as presented here it raises more questions than it answers.

The closing chapters on modern work are informative, and Clegg details his sources well, so you can check the facts for yourself. *Gravity* will do more good than harm, but it may leave you with some confused ideas about the Universe.



JOHN GRIBBIN is a Visiting Fellow in Astronomy at the University of Sussex



Mastermind

How To Think Like Sherlock Holmes

Maria Konnikova

Canongate Books £16.99

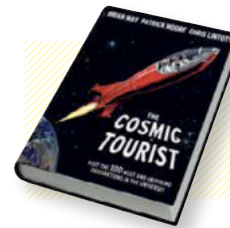
KONNIKOVA USES THE characters of Holmes and Watson as vehicles to convey current psychological perspectives on different modes of reasoning that have been addressed in other books such as Daniel Kahneman's *Thinking, Fast And Slow*. Indeed, they share some examples, though Holmes and Watson provide a cunning narrative to link all the ideas together.

We are told that Holmes is mindful, taking time and effort to observe and process whereas Watson, like most of us, is more mindless, not paying attention and so failing to notice important details. There are good examples of how our reliance on mindless processes can trip us up, as well as some tips about how to become more mindful. One quibble is the use of some metaphors. For example, describing the mind as an attic with limited storage space is scientifically problematic as is the idea that one can throw away memories. Memories are not discreet things to be stored.

However, this should not impair an enjoyable read. Irrespective of whether you are a fan of Sherlock Holmes or not, you should find this book stimulating.



PROF BRUCE HOOD is the author of *The Self Illusion*



The Cosmic Tourist

Visit The 100 Most Awe-Inspiring Destinations In The Universe!

Brian May, Patrick Moore and Chris Lintott

Carlton Books £25

THE COSMIC TOURIST takes you on a journey to see the 100 most awe-inspiring sights in the Universe through the use of the imaginary spaceship 'Ptolemy'. Starting at Earth, the spaceship moves at 'thought-speed' to give us some spectacular views. Through the porthole we see the footprints of the Apollo 11 astronauts on the Moon and the Solar System family members before moving onward to see stars and distant galaxies - travelling all the way to the edge of the observable Universe. The wonderful images are all accompanied by descriptions that cover the science in an accessible way.

But the book is so much more than a scenic, yet informative, tour. It contains down-to-earth advice on how to observe the night sky from the comfort of your armchair, with and without the aid of a telescope, reminding us that even from our Earth-bound location we can all be explorers of the Universe. The book also charts the changing perspectives gained through the development of new techniques, including 'citizen astronomy'.

So, sit back and let Ptolemy's pilots be your guide. This is a fitting testament to the late, great Sir Patrick Moore.



DR LUCIE GREEN is a space scientist based at the Mullard Space Science Laboratory



Secrets Of The Ice

Antarctica's Clues To Climate, The Universe And The Limits Of Life

Veronika Meduna

Yale £29.95

THERE'S A REFRESHING focus to *Secrets Of The Ice*. Antarctic exploration is given just a nod and instead, by celebrating the ground-breaking work of dedicated Antarctic scientists, Meduna reveals some of the most challenging scientific work happening at the moment.

There's an enlightening history of discoveries of the past too, including some that have quite literally saved our skin (our understanding of atmospheric ozone depletion) and others that look to our precarious future. More informative than passionate, Meduna revels in the minutiae of the discoveries made. Seal carcasses

harbour alien communities, anti-freeze leeches live inside frost-proof fish and the fingerprinting of volcanic microbes unlocks the mysteries of our own origins.

The strength of Meduna's writing lies in its confident detailing of the science, rather than poetic prose, and her book grows on you steadily. This is a meticulous look at the science of the southern continent - a confident whispering of secrets revealed, ones that we really should take seriously.



KATHRYN JEFFS is a BBC producer and director whose work includes *Frozen Planet*

Astronomy by Distance Learning



The Liverpool Telescope
La Palma



A Liverpool Telescope
image of M16



Courses running to August 2013

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Write Your Way To A New Career!

Writers Bureau Celebrates Twenty-four Years of Helping New Writers

by Nick Daws

When distance-learning pioneer Ernest Metcalfe founded The Writers Bureau in the late 1980s, he can hardly have dared hope that twenty-four years on it would be acknowledged as Britain's leading writing school. Yet so it proved, with thousands of Writers Bureau students seeing their work in print for the first time. And, for many of those who persevered with their writing, the dream of becoming a successful writer has turned into reality.

Students such as Tim Skelton. An engineer by profession, he had always harboured an ambition to write, and at the age of 40 signed up with The Writers Bureau. The decision changed his life: "My writing career took off exponentially. I started appearing regularly in lifestyle and in-flight magazines. The following year I was commissioned by Bradt Travel Guides to write a guidebook to Luxembourg.

"My writing career took off exponentially."

I've also appeared in The Times and The Independent, and updated guidebooks for Fodor's, Thomas Cook, and the AA."

Another student who benefited was Hazel McHaffie. Hazel wanted to make her academic work in Medical Ethics more accessible to people, and decided to write the themes into novels. Following her Writers Bureau course, Hazel has had five novels published, and appeared at the Edinburgh International Book Festival. She also has her own website at www.hazelmchaffie.com.

Sometimes studying with The Writers Bureau takes students down new and unexpected paths. Patricia Holness originally enrolled on The Writers Bureau's Writing for Children course. However, she soon realised that what she was learning applied to other types of writing as well.

She is now a full-time writer, regularly selling short stories for both children and adults. She also has a monthly column in Devon Life.

Hazel McHaffie



Tim Skelton



These are just a selection from the inspirational true stories from students of The Writers Bureau. There's no reason why YOU couldn't be their next success story. With a 15-day free trial and money-back guarantee, there is nothing to lose and potentially a whole new career to gain! So why not visit their website at www.writersbureau.com or call on Freephone 0800 856 2008 for more information?

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Christina Jones, Oxfordshire

"So far, I have had eighteen novels published. The Writers Bureau helped make this possible for me. Within six months of enrolling on my course I was having work commissioned by editors and I still work regularly for magazines."

Michael Foley, Essex

"Completing The Writers Bureau course has made it possible for me to attain my life-long ambition of becoming a published writer. The level of success I have achieved has far outweighed what I was hoping for when beginning the course. I have now had seventeen books published with two more under publication at the moment."



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How I Improved My Memory In One Evening

The Amazing Experience of Robert Heap

"Of course I place you! You're Bob Humphries of Birmingham."

"If I remember correctly — and I do remember correctly — John Kershaw, the supermarket man, introduced me to you at the dinner of the Bowls Club three years ago in October."

The assurance of this speaker — in the crowded corridor of the Hotel Piccadilly— compelled me to look at him.

"He is Dr. Bruno Furst, the most famous memory expert in the world"

"He is Dr. Bruno Furst, the most famous memory expert in the world," said my friend Keith Clark. "He will show you a lot more wonderful things than that before the evening is over."

And he did.

As we went into the banquet room the toast-master was introducing a long line of guests to Dr. Furst. I got in line, and when it came my turn, Dr. Furst asked, "What are your initials Mr. Heap, your occupation and telephone number?" Why he asked this, I learned later, when he picked out from the crowd the sixty people he had met two hours before and called each by name without a mistake. What's more, he named each person's occupation and telephone number.

"I can teach you the secret of a good memory in one evening"

When I met Dr. Furst he rather bowled me over by saying: "There is nothing miraculous about my remembering anything I want to remember, whether it be names, faces, figures, facts, or something I have read.

"You can do this as easily as I do.

Anyone with an average mind can learn quickly to do exactly the same things."

"That is alright for you, Dr. Furst," I interrupted, "you have given years to it. But how about me?"

"Dramatic Improvement"

"I used to be laughed at in the office here about my poor memory and I must admit with a lot of truth. Since I started your Course my memory has improved out of all recognition!"

Mr. J.W. Sullivan, London S.W.2.

"Mr. Heap," he replied, "I can teach you the secret of a good memory in one evening. This is not a guess, because I have done it with thousands of pupils. In the first of twelve simple lessons which I have prepared for home study, I show you the basic principle of my whole system, and you will find it just like playing a fascinating game. I will prove it to

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Mr. S.N. Caldwell, Huddersfield, Yorkshire.

you."

He didn't have to. His Course did; I got it the next day.

When I tackled the first lesson, I was surprised to find I had learned — in about one hour — how to remember a list of one hundred words so that I could call them off forward and back without a single mistake.



Dr Bruno Furst's Course is fantastic! I can rely on my memory now. I can recall the name of anyone I have met before — and I keep getting better. I can remember any figures I wish. Telephone numbers come to mind instantly. What's more my concentration has improved.

My advice to you is don't wait another minute. You could be astounded to learn what a wonderful memory you have got. Your dividends in both business and social advancement could be enormous.

ROBERT HEAP

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Mr. P.R. Jordan, (Ship's Officer)

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The Darwin Centre, Pembrokeshire



A charity based at Pembrokeshire College, delivering engaging STEM events since 1993. Also operating as the West Wales Branch of the British Science Association.

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Public events ranging from family rock pooling days to lectures on Circadian Clocks (and lots besides). With a new range of exciting public engagement activities in 2013, discover our series of free public lectures and field trips by visiting our website.

www.darwincentre.com

The British Science Festival



The British Science Festival is going nutty about Newcastle next September. We will be gracing the Geordie shores with a science spectacular to remember from 7-12 September 2013.



With the top minds in science heading east, make sure you don't miss out on all the science fun. Whether you want to walk on custard or find out what dark matter really is, make sure you save these dates! Working in partnership with Newcastle University, Northumbria University and Newcastle City Council, events are held across the city, including the Centre for Life.

www.britishtsciencefestival.org

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www.at-bristol.org.uk

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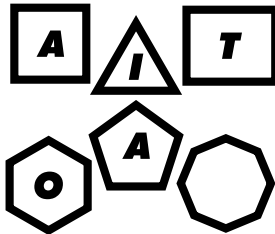
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MINDGAMES

BBC FOUR Pit your wits against these brainteasers by David J Bodycombe, question-setter for BBC Four's *Only Connect*

PRIZE PUZZLE

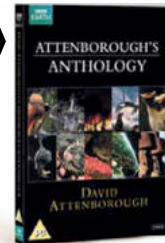
What should appear in the bottom-right shape?



WIN! A DAVID ATTENBOROUGH COLLECTION ON DVD

The first five correct entries win a copy of *Attenborough's Anthology* (BBC, £30).

Post your entry, marked 'Prize Puzzle 251', to: *Focus* magazine, PO Box 501, Leicester, LE94 0AA, to arrive by 5pm on 7 February 2013. We regret that we cannot accept email entries for this competition. See sciencefocus.com/winners for a list of previous winners and solutions.



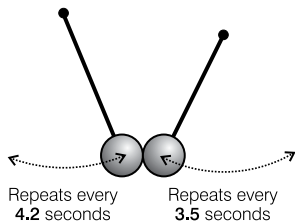
See bottom of p96 for terms and conditions. Congratulations to RF Tindell (Cambridge), Steven Fukes (Norfolk), Chris Kidger-Toole (Derbyshire), Duncan McLean (Newcastle) and Robert Connell who all answered November's Prize Puzzle correctly to win copies of *History Of The World In Two Hours*.

Q1 Who became the first Yorkshire captain to tour Australia, despite never scoring a run or taking a single wicket?

Who became the first Yorkshire captain to tour Australia, despite never scoring a run or taking a single wicket?

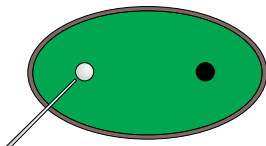
Q2 How long will it be before these free-moving pendulums touch once more?

How long will it be before these free-moving pendulums touch once more?



Q3 The cue ball's starting position and the hole are placed at the two 'focus' points of this oval pool table. What will happen when the ball is struck in a random direction?

The cue ball's starting position and the hole are placed at the two 'focus' points of this oval pool table. What will happen when the ball is struck in a random direction?



Q4 What is the final number in this series: 100, 600, 601, 651, 1651, 1656, ????

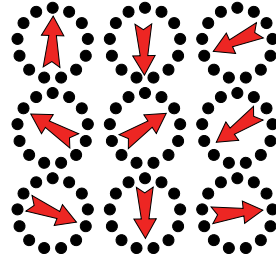
What is the final number in this series: 100, 600, 601, 651, 1651, 1656, ????

Q5 In the *Hitchhiker's Guide* trilogy, we learn that the Ultimate Question is 'What do you get if you multiply six by nine?' and the answer is, famously, 42. In fact, $6 \times 9 = 42$ is justifiable using which number system?

In the *Hitchhiker's Guide* trilogy, we learn that the Ultimate Question is 'What do you get if you multiply six by nine?' and the answer is, famously, 42. In fact, $6 \times 9 = 42$ is justifiable using which number system?

Q6 What are you doing if you solve this code correctly?

What are you doing if you solve this code correctly?



Q7 Which legal distance, used from the end of the 18th century, is said to have derived from the maximum distance a cannon could fire - three nautical miles?

Which legal distance, used from the end of the 18th century, is said to have derived from the maximum distance a cannon could fire - three nautical miles?

Q8 Move the listed cards into the grid so that the best possible poker hand in each row and column matches the label shown. The cards are not necessarily in the right order (eg, 5-4-6-7-3 still counts as a 7-high straight).

Move the listed cards into the grid so that the best possible poker hand in each row and column matches the label shown. The cards are not necessarily in the right order (eg, 5-4-6-7-3 still counts as a 7-high straight).

2♠ 5♠ 6♣ 7♣ 7♠ 9♠ 10♦ 10♠ J♣ J♠
Q♣ Q♠ K♣ K♠ A♠

				8♠	STRAIGHT FLUSH (run of cards in same suit)
5♥	6♥	6♦			FULL HOUSE (pair + 3 of a kind)
4♠		6♠	3♠		FLUSH (all same suit)
	3♦	J♦			2 PAIR
	10♥				2 PAIR
KING HIGH (no pair)	ONE PAIR	ONE PAIR	FLUSH (all same suit)	TEN HIGH (no pair)	

SOLUTIONS

Q1 Captain James Cook, the explorer.
Q2 They will never touch again because some energy will be lost to air resistance. (If we choose to discount friction, they will be back in their starting positions after 21 seconds.)
Q3 No matter which direction you hit the ball at a suitable speed, it will roll into the pocket. The properties of an oval's boundary mean that when the ball strikes the cushion, it will be diverted to the hole at the correct angle.
Q4 1666 - it is the cumulative total of adding together the seven common Roman numerals in alphabetical order: C (100), D (500), I (1), L (50), M (1000), V (5) and X (10).
Q5 Base 13 (ie, $6 \times 9 = 54 = [4 \times 13] + 2$).
Q6 You are ANSWERING the question. That word is spelled out by the nine arrows. The dots and gaps signify the alphabet: A is the dot at the top then, working clockwise, B is the next dot, C is the next gap, D is the next gap etc.
Q7 The traditional limit of the UK's territorial waters. The UK's nautical boundary was extended to 12 nautical miles in 1968.
Q8 See illustration on p96.

QUICK QUIZ

Test your knowledge of human spaceflight

Q1

In what year did Yuri Gagarin become the first man in space?

- a) 1959
- b) 1960
- c) 1961

Q2

Which manned Apollo mission was the first to orbit the Moon?

- a) Apollo 7
- b) Apollo 8
- c) Apollo 9

Q3

What was the name of the first ever space station?

- a) Salyut 1
- b) Skylab
- c) Mir

Q4

Which Space Shuttle broke apart almost immediately after launch in 1986?

- a) Challenger
- b) Columbia
- c) Enterprise

Q5

Who, in 1991, became the first Briton in space?

- a) Michael Foale
- b) Nicholas Patrick
- c) Helen Sharman

Q6

6) How much did Dennis Tito pay for the honour of becoming the first space tourist?

- a) \$10 million
- b) \$20 million
- c) \$30 million

Q7

7) In 2003, which nation became the third to achieve human spaceflight?

- a) China
- b) Japan
- c) India

ANSWERS:

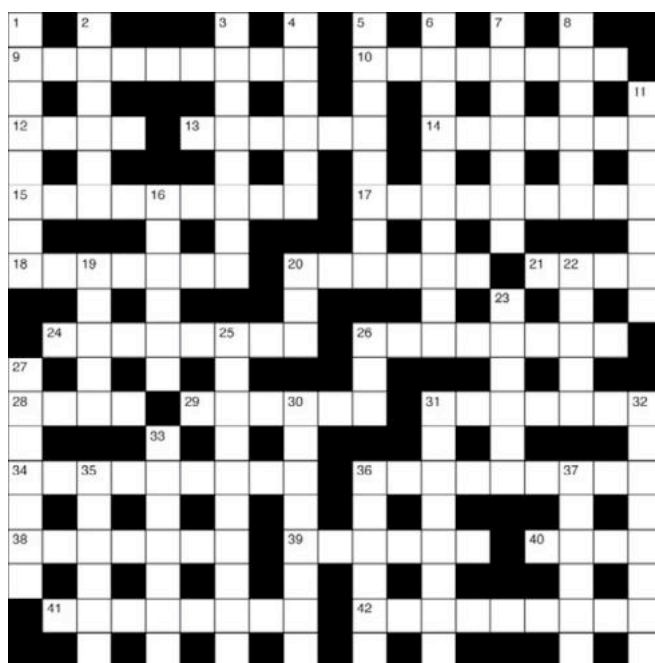
1c, 2b, 3a, 4a, 5c, 6b, 7a

YOU ARE:

- 0-3 A waste of space
- 4-5 Lost in space
- 6-7 Whizzing through space

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ACROSS

- 9 Prisoner can take turns with Frenchman in series (9)
- 10 Answer for every true form of opening (8)
- 12 Weed gets Dutch epitaph (4)
- 13 Draw back from psychiatrist (6)
- 14 Enemy has left after finding diamonds in sheet (3, 4)
- 15 Tree is always eco-friendly (9)
- 17 Cork producer gets help assembling record points (9)
- 18 Main supplier forced to part with nothing (7)
- 20 Second characteristic of a channel (6)
- 21 Row about rite (4)
- 24 Lose a car, sadly, just by the Pacific (5,3)
- 26 Feeder gets cattle to wander around space (8)
- 28 Primate gets kiss at the top (4)
- 29 Inventor is done over (6)
- 31 Control the lizard (7)
- 34 Somehow I crib tome relating to natural data (9)
- 36 Mix tonic in with one key form of acid (9)
- 38 A girl's swayed with only a fire opal (7)
- 39 Seafood provides strength, we hear (6)
- 40 Service part of Einstein's equation (4)
- 41 Hunter distilled a red port (8)
- 42 Terrible slob Alice gets into shape (9)

DOWN

- 1 Rigorous trial for vinegar, say (4,4)
- 2 No different to range of products that's connected (6)
- 3 Exotic fare old president finds awfully tame (8)
- 4 Man managed to charge for part of embryo (6)
- 5 Spiky plant gives bird encouragement (8)
- 6 Turned ripe in hole due to solar proximity (10)
- 7 Expensive, the French spire (7)
- 8 Computer language heard as an introduction (6)
- 11 Engineers gain access on return to Earth (2-5)
- 16 Girl has left former pupil of comprehensive (6)
- 19 Quietly bore about investigation (5)
- 20 Betting on a spring (3)
- 22 Opening trendy permit (5)
- 23 Get man out with attractive object (6)
- 25 I tried sole cooked on meteorite (10)
- 26 Healthy colour in Istanbul (3)
- 27 Attractive girl gets container from mathematician (7)
- 30 Re-invent my core as a tree (8)
- 31 Swimmer seen in the sky (8)
- 32 Halite may sway sailor (4,4)
- 33 Disease spread at the coast (7)
- 35 Model gold railway gets about (6)
- 36 Negative cost involving bacteria (6)
- 37 New university puts a new church in the shade (6)

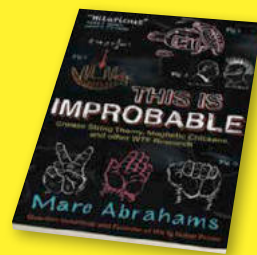
SOLUTION TO CROSSWORD No 144

Lorna Appiah, Joyce Bainbridge, Elizabeth Lucas, John Harvey and A McLellan all solved issue 248's puzzle and each receive a copy of *Attenborough: 60 Years In The Wild* on DVD.



WIN! A COPY OF THIS IS IMPROBABLE

The first five correct solutions drawn will each win a copy of *This Is Improbable* by Marc Abrahams (Oneworld, £10.99). Entries must be received by 5pm on 7 February 2013. See below for details.



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Post entries to: Focus, February 2013 Crossword, PO Box 501, Leicester, LE94 0AA or email a scan of the completed crossword or a list of answers to february2013@focuscomps.co.uk by 5pm on 7 February 2013. Entrants must supply their name, address and phone number. By entering, participants agree to be bound by the terms and conditions printed in full on page 96. Immediate Media, publisher of Focus, may contact you with details of our products and services or to undertake research. Please write 'Do Not Contact' on your email or postal entry if you do not want to receive such information by post or phone. Please write your email address on your postal entry if you would like to receive such information by email.

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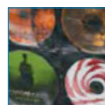


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INTO THE FUTURE

STEPHEN BAXTER

HIVES – COLONIES OF ants or bees, for example – create and sustain living beings in large numbers. In their intricate interdependence, hives are models of Gaia, the global co-operation that underpins life on Earth. But hives seem horrific to us, places of totalitarian control and a loss of individuality. ‘Resistance is futile...’ In *Star Trek* the Borg are a technological hive, with drones interconnected with cybernetic implants. Could there ever be hives of humans?

An insect colony is the most famous biological example of a hive, with a queen, the only ‘mother’, served by ‘drones’, sterile workers. The biologists, rather chillingly, call this way of living eusociality – ‘eu’ meaning ‘perfect’.

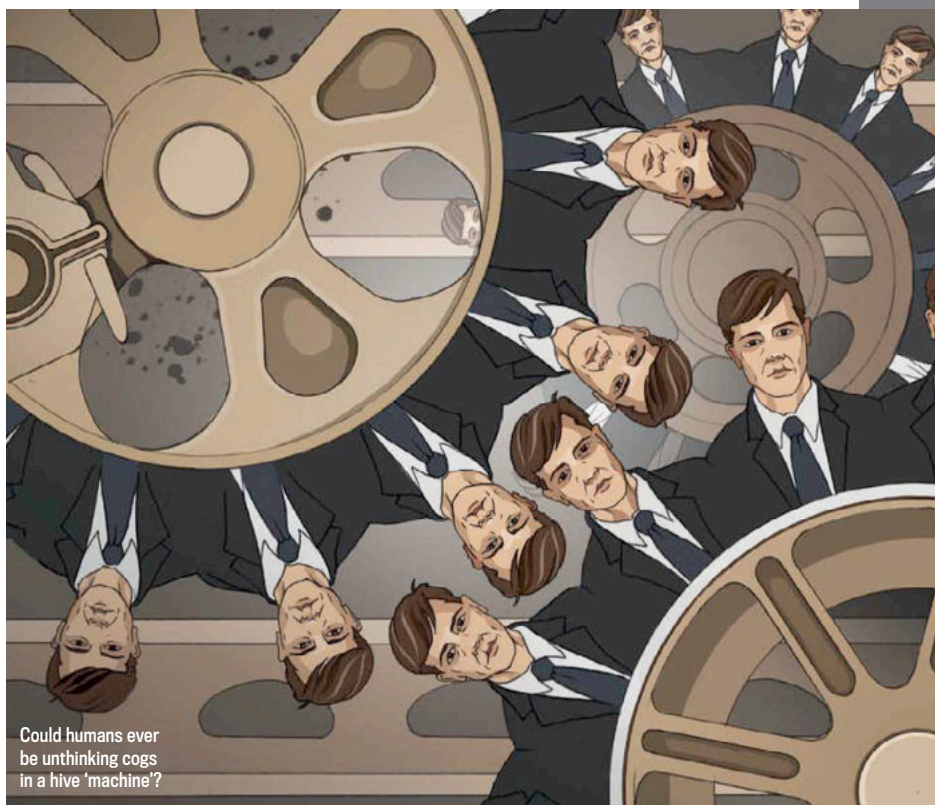
How a hive works is through ‘emergence’. Ants aren’t smart individually, and there’s no one ant in a colony making decisions – not even the queen. Each ant just follows the crowd, picking up on local cues to build a tunnel or bring back food. But out of all those local decisions, the global functioning of the colony emerges. This is emergence: from simple rules, applied at a local level and with some feedback, large-scale structures can ‘self-organise’.

Why a hive works concerns genes. Those sterile workers were an evolutionary puzzle that troubled Darwin: why would the workers bother, if they can’t pass on their own genes to the next generation?

Today there are, in fact, competing theories about hive genetics. According to the theory of ‘kin selection’, evolution is working at the level of the gene, not the individual. Your nieces are less closely related to you than your own daughters. But if, by remaining celibate, you can increase the numbers of your nieces, you may gain overall in terms of genes passed on to the future. Alternatively the theory of ‘multi-level selection’ argues that genetic selection works on two levels, at the level of individuals trying as usual to propagate their genes, and at the level

of a group evolving some characteristic such as close co-operation that gives it some advantage over other groups. Edward O Wilson, perhaps the world’s best-known expert in the subject, has moved from one camp to the other, as described in his recent book *The Social Conquest Of Earth*.

But what about hives of humans? Well, eusociality is not confined to insects. Naked mole rats live in underground colonies beneath the African deserts, digging for tuber roots. In a colony of maybe 40 individuals, at any one time there is only one breeding pair. The others



Could humans ever be unthinking cogs in a hive ‘machine’?

“Imagine a human hive society. It might emerge from a confined group where resources are scarce, such as a colony dome on Mars”

seem to be kept sterile by bullying from the ‘queen’. The mole rats are clearly as eusocial as ants – but they are mammals, just like us.

In human societies, self-organising systems do emerge, all beyond anybody’s control. A traffic jam is an example, a giant organised structure involving maybe thousands of cars emerging from drivers making individual decisions based on what their neighbours are doing. Economies and cities are more sophisticated examples.

As for the genetics, human history has plenty of examples of skewed reproduction. Consider celibacy in the Catholic Church. Nuns, monks and priests sacrifice reproductive chances for the sake of a ‘queen’ – except that the ‘queen’ in this case is a set of ideas, an institution.

Imagine a human hive society, then. It might emerge from a confined group where resources are scarce, such as a colony dome on Mars. In the hive, you would be a cog in a machine that has arisen and runs without conscious purpose at all. And, following your neighbour’s lead, you wouldn’t even know you were a drone.

All this is speculation, of course. Perhaps there can never be hive societies among creatures as self-aware as us. I certainly don’t believe we live in a hive society now. But as a good drone I would say that, wouldn’t I? ■

STEPHEN BAXTER is a science fiction writer whose books include the *Destiny’s Child* series and *The Science Of Avatar*

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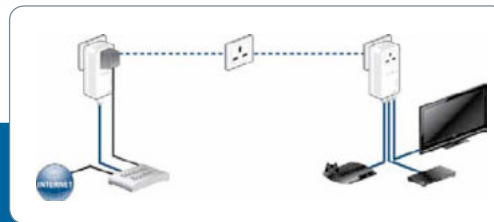
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